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FINAL REPORT

DEVELOPMENT OF THE ARCAS ROCKETSONDE SYSTEM

for
United States Navy
Office of Naval Research
Contract NOnr-2477(00)

FINAL REPORT

DEVELOPMENT OF THE ARCAS ROCKETSONDE SYSTEM

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For:

United States Navy
Office of Naval Research

Contract NOnr-2477(00)

ATLANTIC RESEARCH CORPORATION
Alexandria, Virginia

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PATENT

A patent application has been filed on the Arcas closed-breech launcher described in this report.

FOREWORD

The Arcas rocketsonde system was developed for the Office of Naval Research under contract number Nonr 2477(00). The development was sponsored jointly by the Office of Naval Research and the Air Force Cambridge Research Center through the Office of Naval Research. Additional support was contributed by the U. S. Army White Sands Signal Missile Support Agency, the U. S. Army Signal Research and Development Laboratories, the U. S. Navy Bureau of Ordnance, and others.

Work under this contract began on January 20, 1958, and on March 1, 1959, the contract was extended to cover improvements to the system. This report summarizes all work performed under this contract which was completed December 31, 1959.

SUMMARY

SYSTEM DEVELOPMENT

The Arcas rocketsonde was developed to provide an inexpensive vehicle for conducting atmospheric soundings to an altitude of 200,000 feet. The system, consisting of a rocket vehicle, a launcher, and a parachute recovery system, is capable of carrying a 12.5-pound payload to an altitude of over 200,000 feet.

The rocket employs an end-burning solid propellant grain and a slender vehicle to provide most efficient utilization of propellant energy, maximum loading density, minimum acceleration, and minimum aerodynamic drag. The final vehicle was 92.5 inches long, 4.5 inches in diameter, and weighed 77 pounds fully loaded.

The Arcas motor delivers 336 pounds of thrust for 29 seconds. The 53.75-inch-long grain is encased in a motor tube of 0.04-inch-thick 4130 steel which is insulated with a sleeve of 0.15-inch-thick 41-RPD asbestos-phenolic insulation. One novel feature of the motor design is the tapered integral nozzle attachment system which eliminates a complex nozzle joint and provides significant weight saving. The motor was thoroughly evaluated in static firings, and a 23-round qualification program demonstrated the reliability of the unit.

To accomplish separation of the payload from the vehicle at peak altitude, a separation device was developed which employs a pyrotechnic delay to ignite a gas generating separation charge when the missile reaches peak altitude. This charge expells the parachute and instrument package from the burned-out rocket motor, and the nose cone falls away from the instruments. Both aluminum and plastic nose cones were used successfully, and a volume of 140 in^3 is available for instruments. A parachute was developed which provided an average descent rate of about 275 ft/sec in the 200,000- to 150,000-foot altitude range with a 6.5-pound package.

A unique closed-breech launcher was developed for use with the Arcas system. This unit employs the entrapped exhaust gases of the rocket to accelerate the vehicle by piston action. The launching velocity achieved is governed by the amount of free volume, the length of the launcher tube, and the position and size of bypass vents. Launching velocities of 125 ft/sec were achieved, and both portable and permanently mounted versions of the launcher were produced.

The operational capabilities of the Arcas system were demonstrated in numerous flights, the best of which reached an altitude of 249,000 feet with a full payload. Payload separation and parachute recovery also proved satisfactory.

SYSTEM IMPROVEMENT

A limited program to develop a plastic motor case for the Arcas was undertaken. Fourteen cases of various designs and materials were static-fired, but problems were encountered in insulating and sealing the cases. One successful firing was achieved with a heavy-walled case fabricated of helically and circumferentially wound glass filaments. Subsequent attempts to reduce the wall thickness resulted in failures after 20 to 25 seconds of operation, and the need for better insulating and sealing materials was apparent. The program did not result in a completely successful motor, but it demonstrated that a workable fiber glass motor could be developed and provide a significant weight advantage.

Another program was initiated to improve launching velocity. A larger launcher which provided a launching velocity of 150 to 155 ft/sec was developed. Extensive calculations and testing indicated that the maximum velocity which could be achieved with the basic closed-breech launcher was 165 ft/sec, but that this could probably be increased to 200 ft/sec by using a tie-down mechanism or an auxiliary gas generating system.

The major effort in the extended development program was directed toward developing an extrusion process for Arcas propellant grains to reduce the cost of grain production. Because of the classified nature of the processes involved, a separate report will be issued covering this program.

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INTRODUCTION

The Atlantic Research Corporation developed the Arcas rocketsonde system to provide an inexpensive vehicle for conducting atmospheric soundings to an altitude of 200,000 feet. This system, consisting of a rocket vehicle, a launcher, and a parachute recovery system, is capable of carrying a 12.5-pound payload to an altitude of over 200,000 feet. The Arcas Robin, a shorter version of the Arcas, was developed for a special application and carries a lighter payload to a higher altitude.

After the first successful flights of the Arcas, additional effort was directed toward improvement of the system, specifically, the development of a plastic motor case, the improvement of the launcher, and the development of a continuous extrusion process for propellant grains.

ROCKETSONDE SYSTEM DEVELOPMENT

ROCKET VEHICLE

Vehicle Design

The design of the Arcas sounding rocket was based on the end-burning solid propellant grain configuration, which provides thrust over a relatively long period of time, and thus minimizes acceleration loads. The end-burning technique provides a greater degree of conversion of rocket thrust into vehicle velocity, because a greater portion of the thrust is generated in a less-dense region of the atmosphere, and permits the use of a slender vehicle with minimum aerodynamic drag. Because of the higher propellant loading density, this system provides the smallest vehicle for a given performance requirement.

The Arcas design was based, to some extent, on the Arcon sounding rocket, a larger vehicle which proved the feasibility of the end-burning grain. In the first configuration of the Arcas, a vehicle 78.5 inches long and 4.5 inches in diameter was selected, requiring a fin area of 94 square inches distributed among 4 double-wedge fins. The fins were designed to withstand a load of 70 pounds, equivalent to a yaw of 7 degrees at maximum velocity, and were canted slightly to induce a roll rate of from 1 to 3 rps to offset the effect of any thrust or missile misalignment.

In this vehicle, the stability (the distance between center of pressure and center of gravity) was calculated to be 1.75 calibers at burnout (Mach 3.6) and 3.1 calibers at launch, showing the vehicle to be highly stable. In an end-burning rocket, the center of gravity is shifting forward during most of the propulsive phase of flight, and at the same time, the center of pressure of the vehicle moves forward

as velocity increases. The minimum stability of the missile thus occurs at peak velocity, at which time the center of pressure reaches its most forward point. Because the vehicle reaches its maximum velocity in a less-dense region of the atmosphere, temperatures due to aerodynamic heating were not expected to exceed 700°F at the tip of the nose cone or 750°F at the leading edge of the fins.

After the missile failed to reach design altitude in the first flight tests, the basic design of the vehicle was altered. A longer nose cone was substituted to reduce drag, and the motor and propellant grain were lengthened to provide additional impulse, resulting in an over-all vehicle length of 92.3 inches. The original fin area was considered adequate for this configuration, and the calculated stability at burnout was 1.5 calibers. The 80.8-inch-long Arcas Robin vehicle was marginally stable, but the addition of weight to the forward section, bringing payload weight up to a total of 8.5 pounds, provided 1.5 calibers of stability at burnout. Figure 1 illustrates the final Arcas configuration, and Table I presents the design characteristics of the Arcas and Arcas Robin vehicles. The values for altitude and velocity given in this table are conservative figures based on a sea level launch with a full payload and will, of course, vary with payload, launch altitude, and atmospheric conditions. Figure 2 is a drag curve for the vehicle, Figure 3 illustrates the shift of center of gravity during burning, and Figure 4 presents velocity and acceleration curves.

Rocket Motor

Design and Development

The Arcas rocket motor (Arcas 25-KS-325 MARC 2A1), as originally designed, employed a 3.93-inch-diameter, 47.5-inch-long, end-burning, cartridge-loaded grain of Arcite 373, an aluminum-

containing high-energy propellant; the motor case was fabricated of 0.04-inch-thick 4130 steel by a hydrospin technique, and was insulated with a 0.15-inch-thick molded sleeve of Rocketon X-1[1], an asbestos-filled phenolic material. The novel feature of the case design was the tapered integral nozzle attachment system illustrated in Figure 5; this design avoided a complex nozzle joint and provided a significant weight saving. The head end closure of the motor was secured to a retaining ring which was connected to the motor case by a roll-crimp operation. A flange was provided at the nozzle end of the motor tube for attachment of the pistons required in the launching operation. The design parameters and performance ratings of this motor are summarized below.

Nozzle throat area, in^2	0.255	Average chamber pressure, psi	800
Nozzle exit area, in^2	2.550	Average thrust, pounds	325
Expansion ratio	10	Total impulse, lb-sec	8125
		Action time, seconds	25.0

Nine static firings of this configuration were made in heavyweight test motors, including firings at 110 and -10°F, to evaluate ballistic performance, and seven flightweight motors were static fired prior to initial flight tests, including a five round preliminary flight rating test program involving various environmental conditioning. Other firings were made in short-length test motors to develop a slotted surface geometry for grain ignition, and additional tests led to the development of an inexpensive igniter, which can be separately packaged during shipment and inserted through the nozzle throat before firing. The results of static firings are summarized in Table II.

After the first series of flight tests, it was evident that additional impulse was necessary to meet the altitude requirements; consequently, the rocket motor was lengthened to accommodate a propellant grain 53.75 inches long. The operating pressure was increased

[1] Haveg Corporation.

through adjustment of the nozzle throat diameter, thereby increasing the average thrust and the operating efficiency of the motor.

An additional problem arose when the aluminum powder used in Arcite 373 propellant could not be procured. Several alternate powders were evaluated, and a formulation, Arcite 373D, which was equivalent to Arcite 373 in all performance parameters except burning rate was selected. Attempts to increase the slower burning rate of Arcite 373D by further increase in operating pressure were unsuccessful, and after extensive testing an optimum combination of parameters including an average thrust of 336 pounds over an action time of 29 seconds was selected.

The higher operating pressure and longer burning time of this high-performance motor placed a severe load on the motor insulation. Prior to this design modification, a number of motors insulated with various new materials had been tested in an attempt to locate a better insulating material. One of the insulators tested, a sleeve fabricated from a phenolic-resin-impregnated asbestos felt tape, demonstrated superior insulating properties, and offered weight, strength, and cost advantage over the Rocketon X-1 material. When first tested in the high-performance motor, this material, designated 41 RPD[1], proved only marginal, but subsequent improvements in manufacturing techniques provided a satisfactory insulator which kept motor skin temperatures below 300°F at end of burning in full-length firings.

Other refinements in the design were the incorporation of a new head-closure retaining ring, spot-welded to the motor case, which provided a stronger, lighter-weight structure, and the substitution of four tabs 0.5 inch wide for the flange at the after end of the motor case to reduce vehicle drag. Figure 5 illustrates the details of the final Arcas motor design (Arcas 29-KS-336 MARC 2B1).

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[1] Raybestos Manhattan, Incorporated.

Seven static firings of flightweight motors incorporating all of the modifications were made to thoroughly evaluate the system before qualification. The results of these static firings are included in Table II, and Figure 6 presents typical thrust-time and pressure-time curves for this motor. The design parameters and performance ratings of the motor, designated the 4.5 EX2 MOD 0 rocket motor by the Bureau of Ordnance, are summarized below.

Design Parameters

Motor length, inches	60.7	Insulation thickness, inches	0.15
Grain length, inches	53.75	Nozzle throat area, in^2	0.196
Motor outside diameter, inches	4.45	Nozzle exit area, in^2	2.55
Grain diameter, inches	3.91	Expansion ratio	13
Motor wall thickness, inches	0.04		

Performance Ratings at Sea Level

Characteristic	Temp. °F	Normal Rating	Limits Upper	Limits Lower
Average pressure, psi	-10	805	925	685
	70	1020	1160	850
	110	1150	1325	980
Average thrust, pounds	-10	268	308	228
	70	336	388	284
	110	385	443	327
Total impulse, lb-sec	—	9089	10,859	8759
Action time, seconds	-10	35.4	38.6	32.2
	70	29.0	31.7	26.3
	110	24.8	27.0	22.6

The complete operating specifications are contained in the Model Specification (for limited release) for the 4.5 EX2 MOD 0 Rocket Motor (Type C Arcas), Atlantic Research Corporation Specification No.1, 25 August 1959.

Fins

The aluminum double-wedge fins were inexpensively manufactured by investment casting, and were attached to the missile by a combination of bolting and bonding. Initially, each individual fin was aligned by theodolite, the accuracy of alignment depending to a great extent on the skill of the operator; subsequently a fixture was developed which automatically holds the fins in alignment while the bolting and bonding operations take place, and the task can now be performed by unskilled technicians. This device reduced significantly the time required for fin alignment.

Propellant Grain Fabrication

No serious problems were encountered in casting Arcas grains. Acceptability rates were reasonably good from the start, but some porosity in the grains was encountered. Subsequent refinements in technique, including the development of mold release techniques involving the application of a preinhibitor coating to the mold, and a technique of curing the grain under nitrogen pressure, produced grains of excellent quality.

Qualification Program

Twenty-three flightweight motors of the final design were static fired under various environmental conditions to meet the Bureau of Ordnance requirements for release of the motor for limited experimental use. In addition, three units were fired from the closed-breech launcher to demonstrate the rocket's ability to withstand launching acceleration and exposure to solar radiation and to operate at altitudes above sea level. The environmental testing program is outlined below, and test results are presented in Table III.

Test	Number of Rounds
Ballistic Reproducibility	
110°F	3
70°F	4
-10°F	3
Acceleration (handling)	2
Acceleration (launching)	2
Vibration	2
Temperature cycling	4
Rough road handling	2
Solar radiation and altitude capability	1
Accelerated aging	2

One problem not encountered previously arose during the qualification program when a motor which had been conditioned to -10°F failed on ignition. Examination of the quenched grain showed that the slotted face of the grain had been fractured by the ignition shock. It appeared that stress concentrations in the sharp corners at the base of the slots, aggravated by the brittleness of the propellant at low temperatures, led to the fracture. The base of the slots was rounded to relieve stress concentrations in all subsequent firings Two motors were fired at 40°F to complete the preliminary qualification series, and two additional developmental firings were made at -10°F before proceeding with the qualification program. There was no recurrence of the failure.

One other failure occurred in the qualification series when a motor which had been subjected to rough road handling suffered a case wall burn-through after 27.5 seconds of operation. Subsequent successful rough road handling tests indicated that the failure was not related to the handling. An analysis of the insulating material used in this motor showed the material to be of inferior quality, and close inspection of each insulator received was initiated to avoid a recurrence of this type of failure.

Detailed information on the qualification program is included in the Qualification Test Report (Limited Release) for the 4.5 EX2 MOD 0 Rocket Motor (Type C Arcas), Atlantic Research Corporation, 27 August 1959.

Payload

Parachute Container

In the first configuration of the missile, the parachute container, which comprises the forward portion of the vehicle air frame, consisted of a split aluminum shell attached to the motor case through an overlapping joint. When the separation charge fired, the entire parachute container was blown from the motor, and the halves of the split shell were free to separate, allowing the parachute to open. With this design, difficulty was encountered in maintaining proper alignment of the forward section of the missile, and it was also evident after assembling the first units that the overlapping joint was not strong enough to withstand the aerodynamic loads. Consequently, a complete redesign of the forward section of the missile was accomplished to improve the strength and alignment of the air frame, and to simplify the separation of the parachute and instrument containers.

In the modified design, the parachute was prepacked in a split plastic shell contained within an outer aluminum barrel. The outer container was permanently attached to the rocket motor. The nose cone, with an interlocked instrument base, was connected to the forward parachute closure which was secured in the barrel by shear pins. Separation was accomplished by expelling the inner parachute container from the barrel by piston action. This design was successfully tested in conjunction with the separation device.

Separation Device

The Arcas separation device, developed by the U. S. Flare Division of Atlantic Research Corporation, is a simple gas generator which is housed in the head closure of the rocket motor. A pyrotechnic delay, which is activated as the propellant burns out, ignites the separation charge after a predetermined length of time, allowing the missile to coast to peak altitude before separation. The first device, designed for use with the split parachute container, imparted a relative separation velocity of 15 ft/sec to the package. With the modification of the parachute separation technique, a more powerful separation charge was designed which imparted relative velocities of 50 ft/sec to the package with a maximum acceleration of less than 50 g. The delay interval can be varied during manufacture to accommodate variations in the coast time of the vehicle caused by changes in payload weight or launch altitude.

Nose Cone

The first Arcas nose cone, a 1.5-caliber secant ogive, was abandoned after high drag was encountered in the first series of flight tests. A 4-caliber secant ogive was substituted, providing a considerable reduction in the drag of the vehicle. The longer cone furnished a volume of 140 in^3 for instruments.

A number of materials were used in nose cone fabrication. Aluminum cones with stainless steel tips performed well in several flights, as did cones of glass phenolic and asbestos phenolic. Both plastic cones performed satisfactorily in wind tunnel tests in which they were subjected to Mach 1.5 for 15 seconds, with air preheated to 800°F.

Two methods for attaching the nose cone and instruments to the vehicle were evaluated. In both methods the instruments were secured to the instrument base plate, which was in turn attached to the forward parachute closure by a stud and stop nut. The nose cone was drawn into place by the threading action of the stop nut and stud, and the mating surfaces of the parachute container and nose cone assured proper alignment, making field assembly feasible. In one attachment method, the instrument base was secured to the cone by fingers in the nose cone barrel. While the nose cone was in place with its barrel within the outer parachute container, the fingers gripped the base, but when separation occurred, the fingers were free to spring outward allowing the nose cone to fall away from the instrument package. This design allowed excessive lateral movement of the nose cone. The second method, used with the plastic nose cones, employed a thicker instrument base plate which was attached to the nose cone by six steel balls held in place by the parachute container collar until separation of the package. Upon separation, the balls fell away allowing the nose cone to separate from the instrument package. This design, illustrated in Figure 7, proved more satisfactory.

The Robin Balloon System

A modification of the basic Arcas missile was developed for use in the Air Force Robin program to conduct experiments in measuring atmospheric density by means of a falling sphere. The payload consisted of a one-meter-diameter mylar balloon packaged in a 50-in^3 cylindrical container which was welded into the aluminum Arcas nose cone. The parachute section of the missile was eliminated, and the nose cone was mounted directly on the motor case. Separation of the package was accomplished by a modified Arcas separation device.

Sufficient air was entrapped in the cylinder, which was sealed at sea level, to blow the end closure from the cylinder at high altitudes and eject the balloon; the balloon was then inflated by metered isopentane. Tests of this system were successful. The Robin balloon container is shown in Figure 8.

PARACHUTE

It was necessary to develop a parachute which would be stable in the 200,000-to 100,000-foot altitude range, permitting accurate wind measurement through radar tracking, and which would slow the descent of the package enough to allow recording and transmission of atmospheric data in this region. Little was known about parachute performance at this altitude. After a survey of organizations in the parachute field, a subcontract was awarded to the Radioplane Division of Northrop Aircraft Corporation for the development of a high-altitude parachute.

The contractor developed a 16-foot flying diameter, extended-skirt-type parachute of 0.5-mil mylar material, which was intended to provide a stable descent rate of 300 ft/sec at 200,000 feet with a 6.5-pound load, slowing to 200 ft/sec at 175,000 feet. To assure the opening of the parachute in the rarefield atmosphere at 200,000 feet, a donut-shaped sealed hem was placed around the throat of the parachute; this hem contained methanol which vaporized at high altitudes, inflating the hem to hold the parachute in an open position. Scale models of this design were successfully tested in a vacuum chamber.

Two full-size models of this parachute were tested; one was dropped from a high-altitude balloon at 125,000 feet, and the second was separated from an Arcas missile at 250,000 feet. Both failed to open, and the sealed hem design was abandoned.

A number of baseball-elliptical-type silk parachutes[1], with a 15-foot flying diameter, performed well in flight tests. These

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[1] Manufactured by Gentex Corporation

parachutes employed a bag deployment technique with a line connecting the crown of the canopy to the after-parachute container closure to improve deployment. The surface of the silk was metallized to aid radar tracking. Figure 9 illustrates the details of this parachute configuration. The actual descent rate of the parachute with a 6.5-pound load was found to be about 400 ft/sec at 200,000 feet, 270 ft/sec at 175,000 feet, and 175 ft/sec at 150,000 feet; Figure 10 is the descent curve for the parachute. The silk parachutes were procured in limited quantity for use in production units, but parachutes of other designs and materials will be tested.

LAUNCHER

One of the most significant developments in the Arcas program was the unique closed-breech launcher.[1] Designed to be portable and adaptable, the unit used the entrapped exhaust gases of the rocket to accelerate the missile by piston action. A follower plate, attached to the after end of the rocket, provided a gas seal in the launcher tube, and the rocket was guided in the tube by four lightweight plastic spacers which, with the follower plate, fall away when the unit leaves the launcher. The principle of operation is illustrated in Figure 11. The gases expand into a free-volume cylinder which acts as a gas reservoir, providing a more even application of pressure and minimizing pressure peaks. Bypass vents in the launcher tube can be used to regulate the rate of pressure rise by venting gases during a portion of the rocket's transit of the tube.

The Model I Arcas Launcher, illustrated in Figure 12, was a portable unit mounted on telescoping legs. This launcher, consisting of five major parts weighing less than 400 pounds, could be handled and assembled by two men. The unit could be pivoted into a horizontal

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[1] Patent application pending.

position for breech loading of the round, and could be aimed within a 20-degree verticle cone. The Model II launcher incorporated the main features of the first model, but the base was designed for permanent mounting on a concrete pad.

Test launchings were made with a mockup unit which simulated the weight and dimensions of the Arcas missile and used short propellant charges to provide normal thrust for 0.25 second. The first launcher configuration tested employed an 18,000-in^3 free-volume cylinder and a 10-foot-long launcher tube with bypass vents 50 in^2 in area. A launch velocity of 80 ft/sec with a peak acceleration of 22 g was achieved with this model. In the second configuration, the bypass vents were positioned to close earlier in the launching sequence, and a launch velocity of 110 ft/sec with a peak acceleration of 32 g was measured. Figure 13 presents typical launcher pressure traces for the two configurations. With the increased operating pressure of the modified Arcas motor, the rate of gas generation in the launcher increased, resulting in launch velocities of 125 ft/sec from the same launcher configuration. These tests demonstrated the practicability of the closed breech launcher design, but also indicated that the launch velocity could be improved through further refinement.

To prove the missile capable of withstanding the 32 g shock, several prototype missiles incorporating inert grains with short propellant charges bonded to the end were launched. The results proved that the head-bonded grain could survive the launching shock if adequate clearance were provided to allow some elongation of the grain. This ability of the grain to withstand greater loads than predicted was probably due to the extremely short duration of the peak acceleration loads along with partial support of the grain by chamber pressure.

Launchers constructed for field use retained the major features of the experimental models, but refinements, such as a graduated azimuth ring and a hand-operated locking mechanism, were introduced to facilitate loading and aiming.

FLIGHT TESTING

Performance Flights

Seven flight tests of the Arcas rocket were conducted at the White Sands Missile Range during November 1958 through June 1959. These tests provided a thorough performance evaluation of the Arcas system.

The first three flight tests were of the initial Arcas configuration with the blunt nose cone and shorter motor. The missiles did not carry parachutes, and the parachute containers were permanently attached to the motors. All were launched at an 85-degree angle from the closed-breech launcher with an exit velocity of 80 ft/sec.

The first round was successfully launched, but precession was observed early in the flight, and the missile broke up at 15,000 feet. The erratic flight characteristics were attributed to an excessive roll rate induced by fin misalignment.

The second vehicle was instrumented to measure missile roll rate, pitch and yaw, and motor chamber pressure. The missile followed a stable trajectory but reached a peak altitude of only 78,000 feet. Motor operation was normal, and the peak missile roll rate recorded was 3.34 rps. A maximum yaw of 8.4 degrees was measured as the velocity reached the sonic region, but little yaw was recorded during the rest of the flight.

A third flight was made to confirm the results. This missile followed a stable trajectory, reaching a peak altitude of 90,200 feet.

These tests demonstrated the performance of the propulsion system and the launcher, and established the stability of the vehicle, but a vehicle drag coefficient 80 to 100 per cent higher than anticipated indicated the need for an aerodynamic redesign.

The fourth and fifth flight vehicles incorporated the new 4-caliber secant-ogive nose cone which was expected to reduce vehicle drag by 75 per cent; the rocket motor was not modified. Both missiles were launched at an 85-degree angle and followed normal flight paths, reaching peak altitudes of 178,000 and 171,400 feet respectively. This represented a significant improvement, but modification of the propulsion system was necessary to meet performance requirements.

The fifth and sixth flight units incorporated all of the modifications, including the higher performance motor. Both units carried parachutes, and were rigged for normal payload separation; both were launched at an 85-degree angle with a launching velocity of 125 ft/sec.

The fifth rocket, carrying a silk parachute, functioned normally, but radar contact was lost after 47.5 seconds at an altitude of 130,000 feet. Satisfactory payload separation occurred, and the descending parachute was acquired by radar after 7.5 minutes at an altitude of 130,000 feet. Extrapolation of the available data indicated that the missile reached a peak altitude of no less than 215,000 feet. Useful information on parachute performance was obtained.

The seventh flight unit, carrying a sealed-hem-type mylar parachute was successfully launched, but radar contact was again lost after 100 seconds at an altitude of 219,000 feet. Payload separation occurred, but the parachute failed to open, and the falling payload was acquired by radar after 195 seconds at 195,000 feet. Extrapolation

indicated that a peak altitude of approximately 249,000 feet had been reached.

These tests fully demonstrated the performance capability of the modified rocket vehicle. Figure 14 presents comparative trajectories for the seven performance flights.

Data Gathering Flights

Under the development contract, thirteen additional missiles of the Arcas configuration and twenty-eight units of the Robin configuration were flown to gather meteorological data. Rocket performance was satisfactory in most cases, but only partial success was realized in data acquisition because of instrument failures and difficulty in maintaining radar contact with the vehicle at high altitudes. In earlier flights, three missiles broke up at low altitudes due to fin misalignment, but closer supervision of fin alignment operations was inaugurated to prevent a recurrence. Except for several missiles which performed poorly because of faulty loading procedure or launching under adverse wind conditions, Arcas rockets regularly reached altitudes in excess of 200,000 feet. The best performance in any flight was demonstrated by an Arcas Robin unit which reached an altitude of 280,000 feet. Figure 15 presents data derived from these flights on altitude capability with various payloads.

Wind Effect

The effect of wind on the vehicle during flight is a serious problem in unguided rockets, and in an end-burning unit the low initial velocity makes the missile particularly susceptible to winds in the lower altitudes; about 90 per cent of the total wind effect occurs in the first 2000 feet. This problem can best be minimized by

imparting a high launch velocity to the rocket. With a launch velocity of 100 ft/sec, the Arcas had a total unit wind effect of 4.53 miles displacement per mile per hour of ballistic wind, based on the J. V. Lewis method of wind weighting calculation; increasing the launch velocity to 125 ft/sec reduced this figure to 4.10, and a 150 ft/sec launch velocity reduced the effect to 3.08 miles per mile per hour. These figures are for the basic Arcas unit with a full payload; lighter payload permits the missile to reach higher altitudes, and the total displacement of impact point is greater for the same ballistic wind.

SYSTEM IMPROVEMENT

PLASTIC MOTOR CASE DEVELOPMENT

During the course of the Arcas development program, the feasibility of using plastic materials for the various components of the missile was investigated. These studies indicated that the use of plastics for the nose cone, fins, and parachute container was possible in the existing system, and could result in nominal performance and cost advantages. A more extensive effort was directed toward the study of plastic motor cases, and twelve cases of various designs and materials were tested. Cases fabricated of Spiralloy[1], a structure composed of helically and circumferentially wound glass filaments with an epoxy resin binder, appeared promising. While the study did not result in the development of a completely successful fiber-glass motor case, it did yield convincing evidence that such a case could be developed, and result in a considerable saving in weight of inert parts. Such a case would also make possible the development of a frangible missile which could be destroyed at peak altitude permitting the use of the vehicle over populated areas.

Under the extended development contract, a preliminary case design was completed, based on published strength figures for filament-wound fiber glass pressure vessels. By this time, the operating pressure and burning time of the Arcas motor had been increased; the effect of this change on the fiber glass case was unknown, but it was evident that the modification placed a severe load on the insulation of the metal unit. Although fiber glass itself is an insulator, experience had shown that additional insulation was necessary at the nozzle end of an end-burning rocket where thermal effects were most severe. Design studies demonstrated that a fully insulated chamber

[1] Young Development Division, Hercules Powder Company.

would permit the use of a thinner (0.06-inch) fiber glass wall, resulting in a lighter case, and tape-wound 41-RPD insulation was used. The design retained the tapered nozzle support structure developed in the metal Arcas motor, and employed a technique of attaching the head closure with radial bolts which had been successful in earlier firings.

Cases of a material similar to Spiralloy were procured for testing. These cases were lacking in hoop strength in the tapered boatail region because the manufacturer, Lamtex Industries, was unable to achieve circumferential windings of glass filaments in this area. The first cases suffered delamination and gas leakage through the walls during hydrostatic testing, indicating that a heavier wall and some method of sealing the case were necessary. In subsequent cases, a coating of high-temperature rubber-epoxy adhesive was applied between the insulation and the outer wall, and the wall thickness was gradually increased. The leakage was apparently stopped and the cases survived hydrostatic testing; but all failed when static fired because of either the inability to withstand the shock of rapid pressurization on ignition or weakness in the tapered region. Finally, a case with extra-heavy fiber glass walls was constructed. A separately-formed cone of glass cloth was added to reinforce the tapered area, and the angle of helical windings was changed to 45 degrees to provide a better balance of strength. This case was fired successfully, and provided useful information on the properties of the material.

As it was now evident that the published strength data used in the original design were not applicable to rocket motors, where thermal and shock effects are encountered, a new case design was based on strength figures estimated from the test results. This design, shown in Figure 16, maintained the reinforcing cone and winding angle of the heavy case, and had a wall thickness of 0.18 inch. In other details the design was similar to previous cases. Three of these

cases, weighing approximately 12 to 12.5 pounds each, were tested; each failed due to burn-through of the case wall after 20 to 25 seconds of operation. It appeared that heat transfer through the insulator was sufficient to destroy the rubber-epoxy seal, permitting leakage of hot gas through the case wall.

In a concurrent effort, a number of cases of a different structural character, fabricated by Parallel Products Corporation, were tested. The fiber-glass structure was composed of alternate layers of longitudinally and circumferentially wound glass, a combination that theoretically produces a strong, balanced, structure. The details of the process were not revealed, but it appeared that the cases were not formed by winding individual glass filaments as in the other process, and therefore the full strength of each filament was not realized. Comparative testing indicated that this structure was somewhat weaker than the other product, and no successful firings were achieved with cases of this material. The results of plastic case static firings are summarized in Table IV.

The development effort was halted at this point, and the remaining funds were diverted into extrusion development which promised greater immediate benefits.

The development of a plastic motor case proved more difficult than anticipated. Because the original feasibility study was made under less severe rocket-motor operating conditions it did not give a clear indication of the problems. The major sources of difficulty were the tapered nozzle support design and the use of over-optimistic strength figures in the original design. These problems were overcome, and the program did demonstrate that a workable fiber-glass motor case could be developed. This case, based on present knowledge, would weigh 13 to 13.5 pounds as contrasted with the 18 pounds of metal parts it replaces, and still promises a significant

performance advantage along with the possibility of a frangible unit. The remaining problems could probably be eliminated through the use of a sealing material with better temperature capabilities, or through a slight increase in insulator thickness, but considerable additional testing would be necessary to produce a dependable motor.

LAUNCHER IMPROVEMENT

During the Arcas development, it became apparent that a higher launching velocity would be desirable, to reduce the wind dispersion of the vehicle and to make the system operational over a wider range of conditions. The goal of the launcher improvement program was to attain a launch velocity of 150 ft/sec with a maximum acceleration less than 50 g, and to study the feasibility of attaining velocities in the vicinity of 200 ft/sec.

Extensive theoretical calculations were performed on the effect of free volume, size and location of by-pass area, and length of the launching tube on launch velocity and acceleration. Selected results are presented below.

Free Volume, in^3	Maximum Acceleration, g	Average Acceleration, g	Velocity, ft/sec 15-ft Tube	20-ft Tube	25-ft Tube
55,000	31.9	19.8	161	191	214
40,000	32.6	21.0	168	195	216
25,000	33.0	22.2	170	197	217

From these data, it was apparent that little would be gained by increasing the free volume above 25,000 in^3. The acceleration values presented here are incorrect because of an inaccuracy in the calculations; values about 15 per cent higher would be more reasonable. Figure 17 is a plot of theoretical launching velocity versus launcher

tube length, and theoretical acceleration in a launcher with 25,000 in^3 free volume. Calculations also showed that venting of gases reduced acceleration with accompanying loss of velocity. Friction was not considered in the calculations.

The 25,000-in^3 volume was selected as the maximum for testing, and a heavy-walled free-volume cylinder of this size was constructed. This unit incorporated plugs of flame resistant plastic to permit variation of the volume in 5000-in^3 increments. Difficulty was encountered in obtaining aluminum launcher tubes which met straightness and roundness requirements. The feasibility of a fiber glass tube was investigated, but the cost was prohibitive. Finally, a satisfactory tube fabricated in 8-foot sections joined with flanges was procured; this system permitted easy variation of the tube length during testing.

The results of test launchings are summarized below.

Free Volume (in^3)	Tube Length (ft)	Special Modification	No. of Tests	Average Acceleration (g)	Maximum Acceleration (g)	Launching Velocity (ft/sec)
25,000	20	--	4	24	41	155
25,000	16	--	2	25	39	156
20,000	20	--	2	25	45	162
20,000	15	--	3	30	47	153
20,000	15	25-in^2 vent area	4	23	36	133
20,000	16	solid pistons	2	30	47	165
15,000	20	--	2	14	24	135

These tests demonstrated that the gain in performance resulting from a free volume greater than 20,000 in^3 was not enough to justify the extra bulk and weight involved, and that increasing the length of the launcher tube beyond 15 feet provided little improvement in velocity; the pressure in the system fell so rapidly that little acceleration was applied during the transit of the last 5 feet of a

20-foot-long tube. Figure 18 presents launcher pressure curves for two configurations of the closed-breech launcher. The combination of 20,000 in^3 free volume with a 15-foot-long tube was selected as optimum. This configuration delivered an average launching velocity of 153 ft/sec with a peak acceleration of 30 g. Velocity measurements, made by high-speed motion picture photography, were accurate within ±3 ft/sec, and velocities normally varied by ±5 ft/sec between launchings because of differences in friction. Test launchings of prototype missiles with full-length inert grains proved the system capable of withstanding the acceleration.

The difference between the theoretical and actual performance of the launcher was attributed to the effect of friction, and, as much of the friction was believed to be due to the split piston arrangement, two tests were completed using solid pistons. The launch velocity increased by only 10 per cent, not enough to justify the use of the solid pistons which would require a complicated attachment mechanism.

Before this test program was completed, it became necessary to deliver a launcher for meteorological firings. A configuration combining a 20,000-in^3 free volume with a 15-foot-long tube and a bypass vent area of 25 in^2 was used. This launcher provided a launching velocity of 133 ft/sec with a maximum acceleration of 36 g.

The design of the Model 3 Arcas launcher, shown in Figure 19, was completed using the combination of 20,000-in^3 free volume and a 15-foot-long tube without venting. This model, designed for permanent installation, used domed heads on the free-volume cylinder and employed a launcher tube fabricated in two sections for easier handling. The launcher was supported by an A-frame structure near its center of gravity for ease of elevation and depression, and refinements were introduced in the elevation adjustment and breech closing mechanisms.

It appears that the maximum velocity which can be achieved with the basic closed-breech launcher is 160 to 165 ft/sec. Tests and calculations have shown that further increase in free volume and tube length have only a small effect on velocity. The velocity could probably be increased to 200 ft/sec or more through the introduction of a mechanism to retard the rocket during initial burning to permit pressure buildup in the cylinder before movement of the rocket, or through the use of an auxiliary gas generating system in the launcher.

EXTRUSION DEVELOPMENT

The development of a continuous extrusion process for Arcas grains would significantly reduce the cost of the Arcas in quantity production. In the casting of grains, many man-hours were spent in individual hand operations which would be eliminated in an extrusion process. Previous work in the extrusion of Arcite propellants provided a background of information. The goal of this program was to develop and refine, to the extent possible within the time and fund limitations, a process for extruding Arcas propellant grains. Because of the classified nature of the processes involved, a separate report will be issued covering this program.

CONCLUSION

The Arcas system, in its final configuration, has proven fully capable of meeting the performance requirements. The reliability of the rocket motor has been confirmed through extensive static testing, and the operational capabilities of the system have been demonstrated in numerous flights The practicability of the closed-breech launcher design has been proven.

Under the improvement program, a fully successful plastic motor case was not developed, but the feasibility of a plastic missile was demonstrated, and considerable progress was made toward the development of an operational plastic unit. The launcher improvement program reached its goal and pointed out probable methods of further increasing the launching velocity.

Arcas is now being produced in limited quantities, and efforts toward system improvement and cost reduction are continuing.

TABLES

TABLE I. DESIGN CHARACTERISTICS OF THE ARCAS ROCKET

Basic Arcas Configuration

Dimensions	
Length, inches	
Over-all	92.3
Motor	60.8
Parachute housing	13.4
Nose cone	18.1
Diameter, inches	4.45
Volume, in^3	
Instrument compartment	170
Parachute container	140
Fin area-4 fins, in^2	94
Weight, pounds	
Payload total, nominal	12.0
Instruments	6.5
Nose cone	1.5
Parachute	2.5
Parachute housing	1.5
Rocket motor and fins	64.5
Separation device	0.5
Total vehicle weight	77.0
Burnout weight	36.0
Performance	
Maximum altitude (with 12.5-pound payload), feet	210,000
Time to maximum altitude, seconds	128
Maximum velocity, ft/sec	3650
Altitude at burnout, feet	47,300
Launch velocity, ft/sec	150
Acceleration at launch, g	40

Arcas Robin Modification

Dimensions	
Length, inches	
Over-all	80.8
Motor	60.8
Nose cone	20.0
Container volume, in^3	52
Weight, pounds	
Payload total	8.5
Balloon	0.3
Nose cone, container, and ballast	8.2
Rocket motor and fins	64.5
Separation device	0.5
Total vehicle weight	73.5
Burnout weight	32.5
Performance	
Maximum altitude, feet	268,000
Time to maximum altitude, seconds	147
Maximum velocity, ft/sec	4100
Altitude at burnout, feet	50,800
Launch velocity, ft/sec	160
Launch acceleration, g	47

TABLE II. SUMMARY OF ARCAS DEVELOPMENTAL STATIC FIRINGS

Test Number	Purpose of Test	Loading	Test Results: Average Chamber Pressure (psi)	Average Thrust (pounds)	Action Time (seconds)	Remarks
Static Tests of Heavyweight Test Motors						
AH-1	Ballistic evaluation	43.75-inch-long Arcite 373 grain inhibited with PUX-500. 0.57-inch-diameter nozzle throat. Rocketon X-1[a] insulation	—	298	22.8	Thrust value of questionable accuracy
AH-2	Ballistic evaluation	Same as AH-1 except 42.75-inch-long grain	868	280	22.5	Thrust value of questionable accuracy
AH-3	Ballistic evaluation	Same as AH-1 except 46-inch-long grain	880	372	23.1	Thrust measurement questionable
AH-4	Ballistic evaluation	Same as AH-3	1025	330	20.8	Thrust measurement questionable
AH-5	Ballistic evaluation	Same as AH-3	931	359	21.6	Satisfactory test
AH-6	Ballistic evaluation	Same as AH-3	871	—	23.4	No usable thrust data
AH-7	Performance evaluation at -10°F	Same as AH-1 except for 45-inch-long grain	734	335	24.8	Satisfactory test
AH-8	Performance evaluation at 110°F	Same as AH-3	—	—	—	Failed due to faulty assembly
AH-9	Performance evaluation at 110°F	Same as AH-3	880	330	23.0	Satisfactory test. Thrust measurement questionable
AH-10	Evaluation of separation device	Same as AH-3 except that separation device was included	—	—	—	Failed because of faulty assembly
AH-11	Evaluation of separation device	Same as AH-10	875	315	23.4	Separation device performed satisfactorily. Thrust measurement questionable
AH-12	Evaluation of 41-RPD insulation[b]	Same as AH-3 except that 41-RPD insulation was used	853	337	23.7	Insulation performed well
AH-13	Evaluation of 41-RPD insulation[c]	Same as AH-12	—	—	—	Failed because of thin inhibitor on grain
AH-14	Evaluation of ARF insulation[d]	Same as AH-3 with ARF insulation	710	312	26.5	Insulation performance fair

TABLE II (Continued)

Test Number	Purpose of Test	Loading	Test Results: Average Chamber Pressure (psi)	Average Thrust (pounds)	Action Time (seconds)	Remarks
AH-15	Evaluation of ARF insulation	Same as AH-14	775	330	24.6	Insulation performance fair
AH-16	Evaluation of 41-RPD insulation[c]	Same as AH-13	785	365	23.0	Insulation performance fair
AH-17	Evaluation of diethal-inhibited grain	47.5-inch-long grain inhibited with diethal	—	—	—	Inhibitor failed
AH-18	Evaluation of foamed neoprene inhibitor	33.75-inch-long grain inhibited with foamed neoprene rubber	—	—	—	Inhibitor failed
AH-19	Evaluation of Arcite 373D propellant with higher operating pressure	47.75-inch-long grain of Arcite 373D. Nozzle throat diameter of 0.50 inch	1033	345	25.4	Severe nozzle erosion, highly regressive pressure trace, slow burning rate
AH-20	Shelf-life evaluation and evaluation of AA insulation[d]	44.75-inch-long, 7-month-old grain of Arcite 373, nozzle throat diameter 0.50 inch	1380	472	17.5	Pressure and burning rate higher than normal, but test satisfactory. Insulation performance good.
AH-21	Evaluation of foamed neoprene inhibitor	Same as AH-18	—	—	—	Inhibitor failed
AH-22	Evaluation of Arcite 373D at 110°F	Same as AH-19	1113	373	23.4	Satisfactory
AH-23	Evaluation of Arcite 373D at 110°F	Same as AH-19	1153	387	22.9	Satisfactory
AH-24	Evaluation of Arcite 373A propellant	47.75-inch-long grain of Arcite 373A. 0.50-inch-diameter nozzle throat	1154	376	21.6	Satisfactory operation but poor impulse
AH-25	Evaluation of Arcite 373A at 110°F	Same as AH-24	1250	400	20.0	Satisfactory operation but poor impulse
AH-26	Evaluation of Arcite 373D at -10°F	44.75 inch-long grain of Arcite 373D. 0.50-inch-diameter nozzle throat	790	235	31.7	Satisfactory
AH-27	Evaluation of Arcite 373A at -10°F	Same as AH-26 except Arcite 373A propellant used	998	255	26.2	Satisfactory operation but poor impulse

TABLE II (Continued)

Test Number	Purpose of Test	Loading	Test Results: Average Chamber Pressure (psi)	Average Thrust (pounds)	Action Time (seconds)	Remarks
AH-28	Evaluation of Arcite 373A propellant and AA insulation[d]	Same as AH-27 with AA insulation	1108	390	20.0	Poor impulse. Good insulation performance
AH-29	Same as AH-28	Same as AH-28	1239	408	19.5	Poor impulse. Good insulation performance

In addition, 17 firings were made in 13-inch-long heavyweight test motors to evaluate various grain ignition surface geometries, and in developing the Arcas igniter.

		Static Tests of Flightweight Motors				
AL-1	Evaluation of flightweight motor	0.40-inch-thick 4130 steel tube with Rocketon X-1[a] insulation. 46-inch-long grain of Arcite 373, inhibited with PUX-500. 0.57-inch-diameter nozzle throat	—	300	24.4	Performance satisfactory but thrust value questionable
AL-2	Evaluation of flightweight motor	Same as AL-1	—	290	22.7	Thrust value questionable
AL-3	Evaluation of flightweight motor	Same as AL-2	1047	384	20.5	Thrust and pressure values questionable
AL-4	Preflight evaluation	Standard loading with 47.5-inch-long grain; accelerated to 20g on ballistic centrifuge before firing	775	306	25.1	Satisfactory
AL-5	Evaluation of 41-RPD insulation[b]	Same as AL-4; 41-RPD insulation	—	365	21.3	Satisfactory. Good insulation performance
AL-6	Preflight evaluation	Same as AL-4; fired at 110°F	—	—	—	Failed due to faulty weld in motor case
AL-7	Preflight evaluation	Same as AL-4; cycled between -10°F and 110°F before firing; fired at 110°F	901	365	21.2	Satisfactory
AL-8	Preflight evaluation	Same as AL-4; fired at -10°F after rough-road handling	792	280	26.9	Satisfactory

TABLE II (Continued)

Test Number	Purpose of Test	Loading	Test Results: Average Chamber Pressure (psi)	Average Thrust (pounds)	Action Time (seconds)	Remarks
AL-9	Evaluation of 41-RPD insulation[c]	Same as AL-5	828	315	20.8	Fair insulation performance. Thrust value questionable
AL-10	Evaluation of 41-RPD insulation[c]	Same as AL-5	850	340	22.8	Fair insulation performance
AL-11	Evaluation of ARF insulation[d]	Same as AL-4 with ARF insulation	875	360	22.8	Fair insulation performance
AL-12	Evaluation of ARF insulation	Same as AL-11	830	320	23.7	Fair insulation performance
AL-13	Evaluation of modified motor	53.75-inch-long Arcite 373 propellant grain; improved 41-RPD insulation; 0.50-inch-diameter nozzle throat	—	380	23.6	Satisfactory; good insulation performance
AL-14	Evaluation of modified motor	Same as AL-13	980	374	25.9	Satisfactory
AL-15	Evaluation of modified motor with Arcite 373D propellant	Same as AL-13 with Arcite 373D grain	—	323	28.8	Slow burning rate, highly regressive curve. Severe erosion of nozzle
AL-16	Same as AL-15	Same as AL-15 but nozzle throat diameter decreased to 0.48 inch	—	—	—	Failed due to faulty assembly
AL-17	Same as AL-15	Same as AL-15, new graphite used in insert	—	350	29.6	Slow burning rate, regressive, nozzle erosion reduced somewhat
AL-18	Same as AL-15	Same as AL-17	—	—	—	Failed due to faulty assembly
AL-19	Same as AL-15	Same as AL-17	—	371	26.8	Slow burning rate, regressive, nozzle erosion reduced somewhat
AL-20	Same as AL-15	Same as AL-17	—	360	27.9	Same as AL-19
AL-21	Evaluation of final motor configuration	53.75-inch-long grain of Arcite 373D propellant, 41-RPD insulation, 0.50-inch-diameter nozzle throat	—	400	25.0	Thrust value doubtful; satisfactory operation
AL-22	Evaluation of final configuration	Same as AL-21	—	325	29.2	Satisfactory performance
AL-23	Evaluation of final configuration at -10°F	Same as AL-21	—	240	36.5	Satisfactory performance

TABLE II (Continued)

Test Number	Purpose of Test	Loading	Test Results: Average Chamber Pressure (psi)	Average Thrust (pounds)	Action Time (seconds)	Remarks
AL-24	Same as AL-23	Same as AL-21	—	285	34.2	Satisfactory performance
AL-25	Evaluation of Arcite 373A propellant	Same as AL-21 with Arcite 373A propellant	—	370	25.9	Poor impulse.

[a]Product of Haveg Industries.

[b]Raybestos-Manhattan, Inc., material; fabricated by Young Development Laboratories.

[c]Fabricated by Raybestos-Manhattan, Inc.

[d]Product of Synthane Corporation.

TABLE III. ARCAS QUALIFICATION TEST RESULTS

Static Tests

Test No.	Conditioning	Firing Results: Average Thrust (pounds)	Firing Results: Action Time (seconds)	Remarks
AQ-1	Acceleration, 70°F	321	29.8	Satisfactory
AQ-2	Vibration, 70°F	308	29.9	Satisfactory
AQ-3	Temperature cycled	339	29.3	Satisfactory
AQ-4	110°F	371	25.0	Satisfactory
AQ-5	-10°F	—	—	Failed on ignition
AQ-6	Rough-road-handling, 70°F	—	—	Failed after 27.5 seconds
AQ-7	70°F	348	28.8	Satisfactory
AQ-8	Rough-road-handling, 40°F[a]	326	28.9	Satisfactory
AQ-9	40°F[b]	319	31.6	Satisfactory
AQ-10	Acceleration, 70°F	310	29.9	Satisfactory
AQ-11	Vibration, 110°F	368	25.7	Satisfactory
AQ-12	Vibration, -10°F	281	36.5	Satisfactory
AQ-13	Vibration, 70°F	324	29.3	Satisfactory
AQ-14	Temperature cycled	373	27.8	Satisfactory
AQ-15	Temperature cycled	342	28.4	Satisfactory
AQ-16	Temperature cycled	351	29.9	Satisfactory
AQ-17	Rough-road-handling, 70°F	341	28.4	Satisfactory
AQ-18	Rough-road-handling, 70°F	337	29.2	Satisfactory
AQ-19	Rough-road-handling, 70°F	349	28.1	Satisfactory
AQ-20	-10°F	295	34.0	Satisfactory
AQ-21	-10°F	277	35.9	Satisfactory
AQ-22	110°F	412	24.2	Satisfactory
AQ-23	70°F	320	30.7	Satisfactory

Launching Tests

Test No.	Purpose	Results
1	Prove ability to withstand launch acceleration	Satisfactory
2	Prove ability to withstand solar radiation and function at altitudes above sea-level	Satisfactory
3	Same as 2	Satisfactory

[a]Fired as an interim replacement for AQ-6.

[b]Fired as an interim replacement for AQ-5.

TABLE IV

TESTS OF ARCAS PLASTIC MOTOR CASES[a]

Test No.	Case Structure	Wall Thickness (inches)	Insulation	Case Weight (pounds)	Sealing Material	Test Results
—	Spiral winding.[b]	0.054	41-RPD.[c]	7.3	None	Failed pressure test; not fired.
—	Spiral winding.	Tapered 0.85 Ave.	Partial 41-RPD.	7.7	None	Failed pressure test; not fired.
AF-13	Longitudinal and circumferential winding.[d]	0.10	Asbestos roving.	9.2	Rubber.	Failed on ignition.
AF-14	Spiral winding.	0.08	41-RPD.	8.7	Rubber-epoxy adhesive.	Failed on ignition.
AF-15	Same as AF-13.	0.13	Asbestos roving.	10.8	Rubber.	Insulation failure, 4 seconds.
AF-16	Same as AF-13.	0.15	Asbestos roving.	12.3	Rubber.	Insulation failure, 2 seconds.
AF-17	Spiral winding.	0.11	41-RPD.	10.5	Rubber-epoxy adhesive.	Failed in tapered area.
AF-18	Same as AF-13.	0.18	Asbestos roving.	13.5	Rubber.	Failed at head-end, 2 seconds.
AF-19	Same as AF-13.	0.15	Asbestos roving.	12.5	Rubber.	Insulation failure, 4 seconds.
AF-20	Spiral winding with reinforced tapered area.	0.21	41-RPD.	15.7	Rubber-epoxy adhesive.	Successful.
AF-21	Same as AF-13.	0.18	41-RPD.	13.0	Rubber.	Failed after 24 seconds; probable crack in insulation.
AF-22	Same as AF-13.	0.15	41-RPD.	12.3	Rubber.	Head-end failure.
AF-23	Same as AF-13.	0.18	41-RPD.	13.9	Rubber.	Wall failure, 4 seconds.
AF-24	Spiral winding with reinforced tapered area.	0.18	41-RPD.	12.4	Rubber-epoxy adhesive.	Failed after 22 seconds, probably because of breakdown of sealing materials.
AF-25	Same as AF-24.	0.18	41-RPD.	12.1	Same as AF-24.	Same as AF-24, 24 seconds.
AF-26	Same as AF-24.	0.18	41-RPD.	11.9	Same as AF-24.	Same as AF-24, 23 seconds.

[a]This summary does not include tests AF-1 through 12 conducted during the initial feasibility study.

[b]All spirally wound cases were fabricated by Lamtex Industries.

[c]Raybestos-Manhattan, Incorporated.

[d]Fabricated by Parallel Products Corporation.

FIGURES

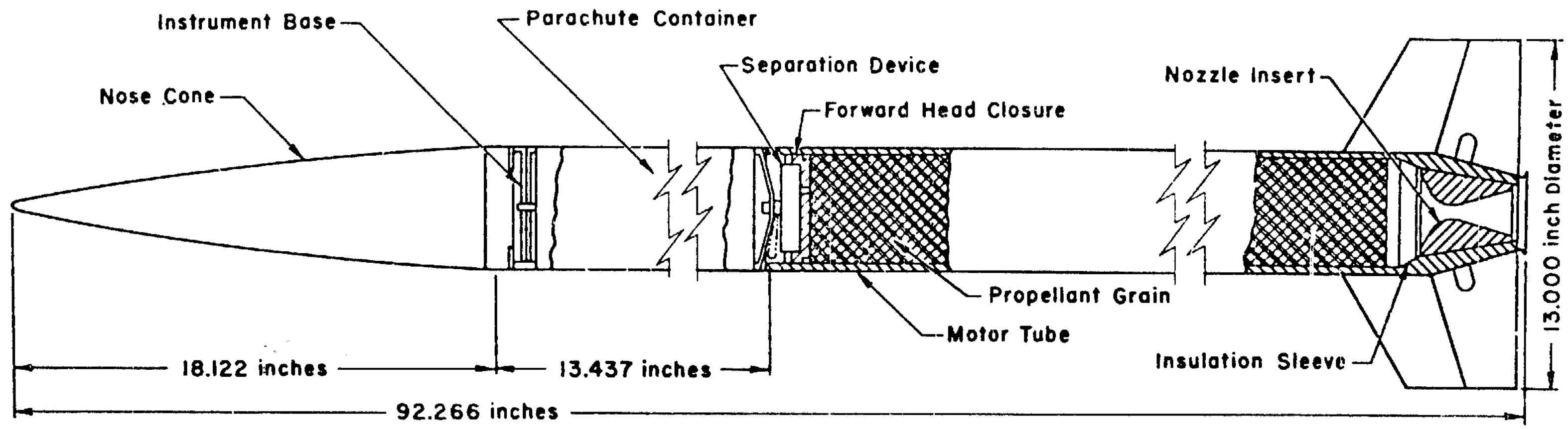

Figure 1. Arcas General Configuration.

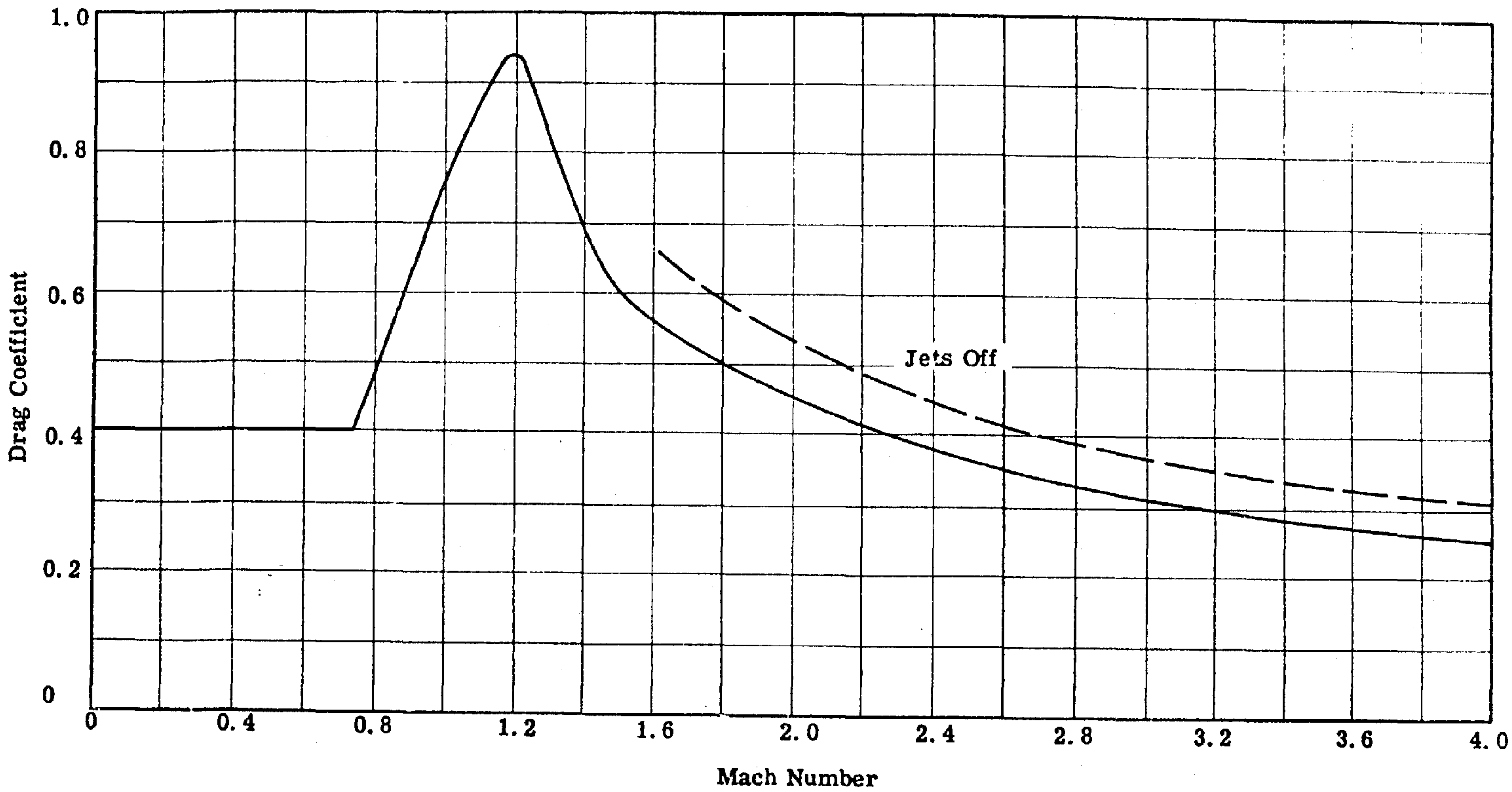

Figure 2. Drag Coefficient of the Final Arcas Aerodynamic Configuration.

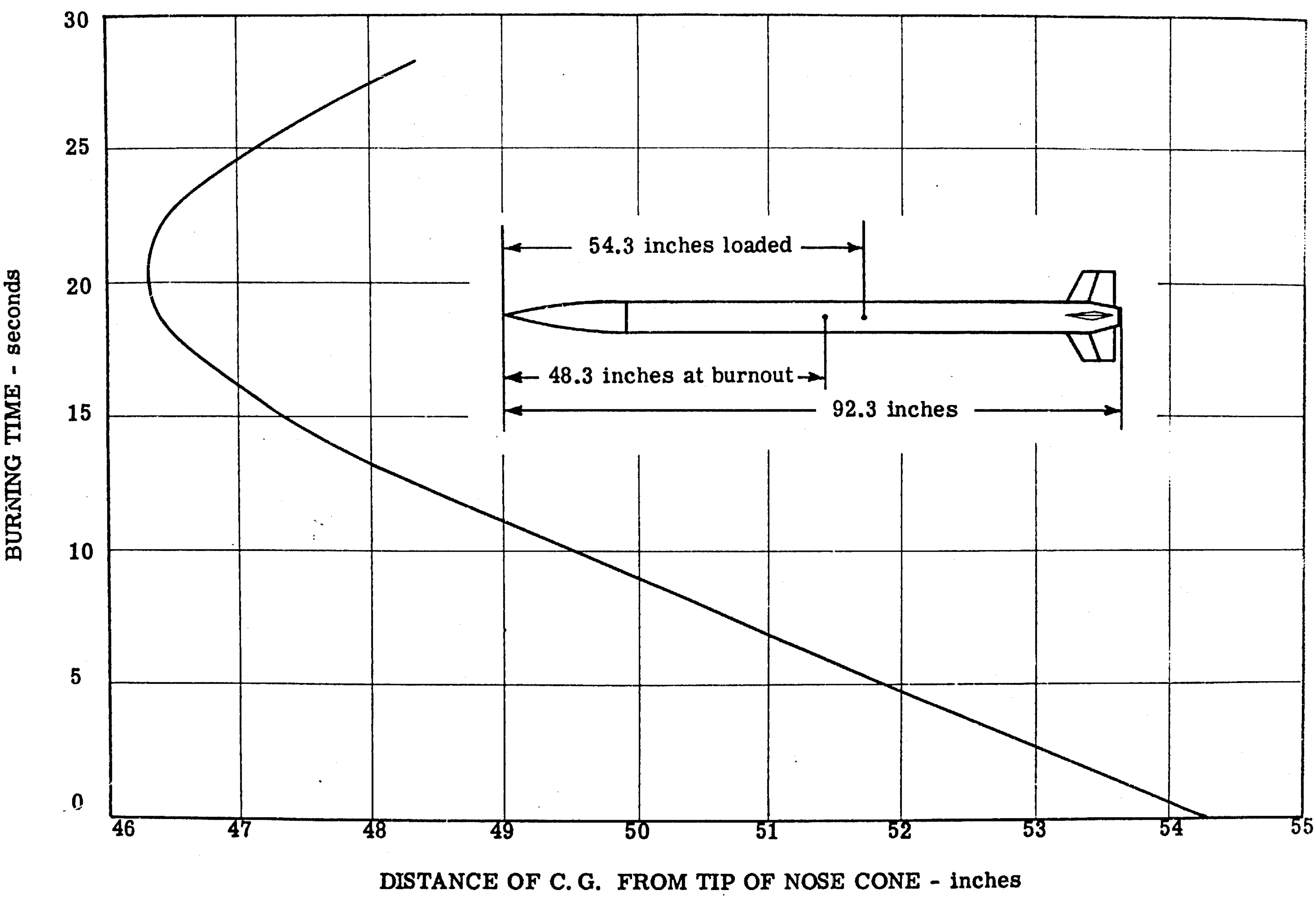

Figure 3. Shift of Center of Gravity in the Arcas Rocket.

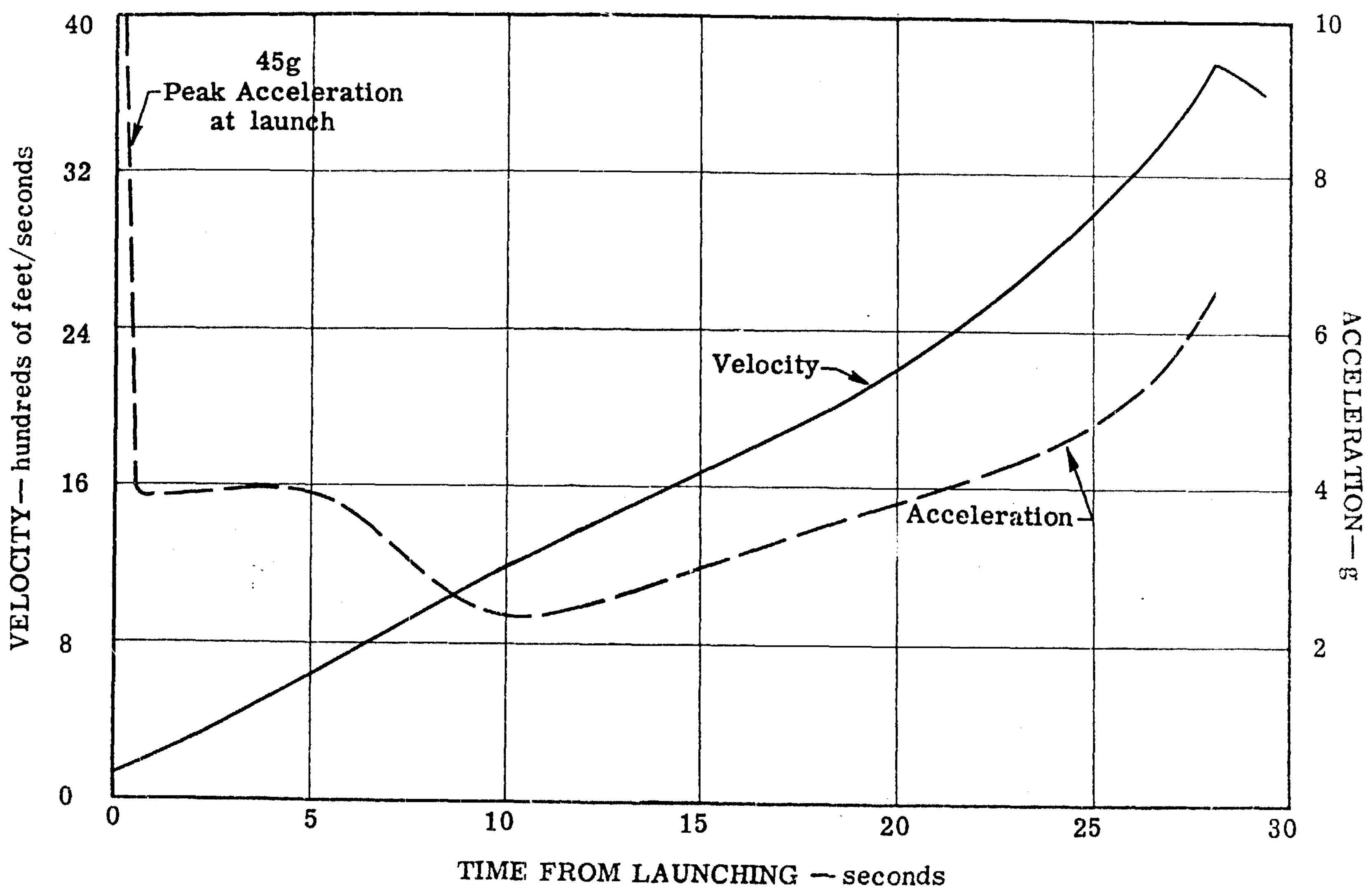

Figure 4. Velocity and Acceleration Curves for the Arcas Rocket.

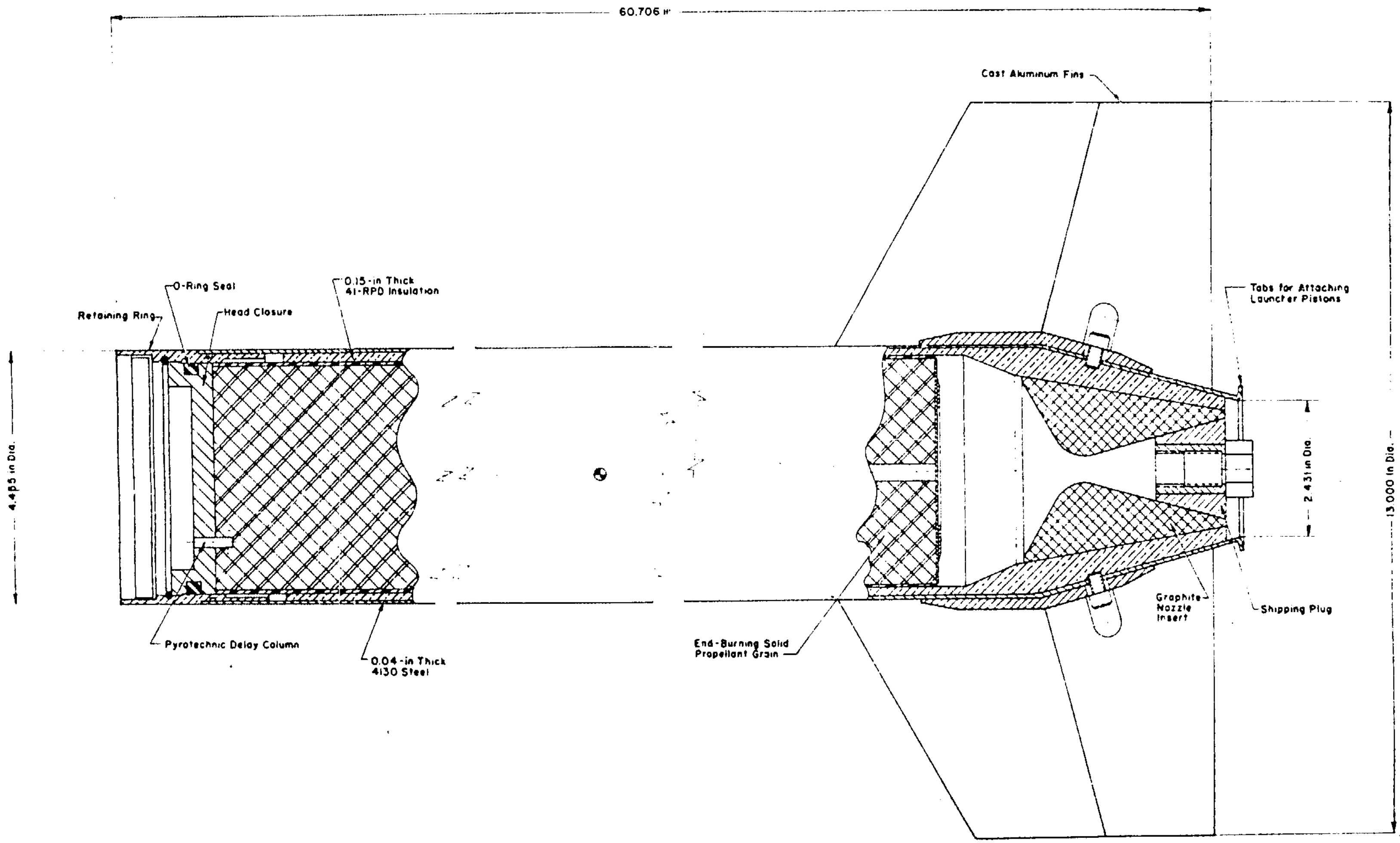

Figure 5. Arcas Motor.

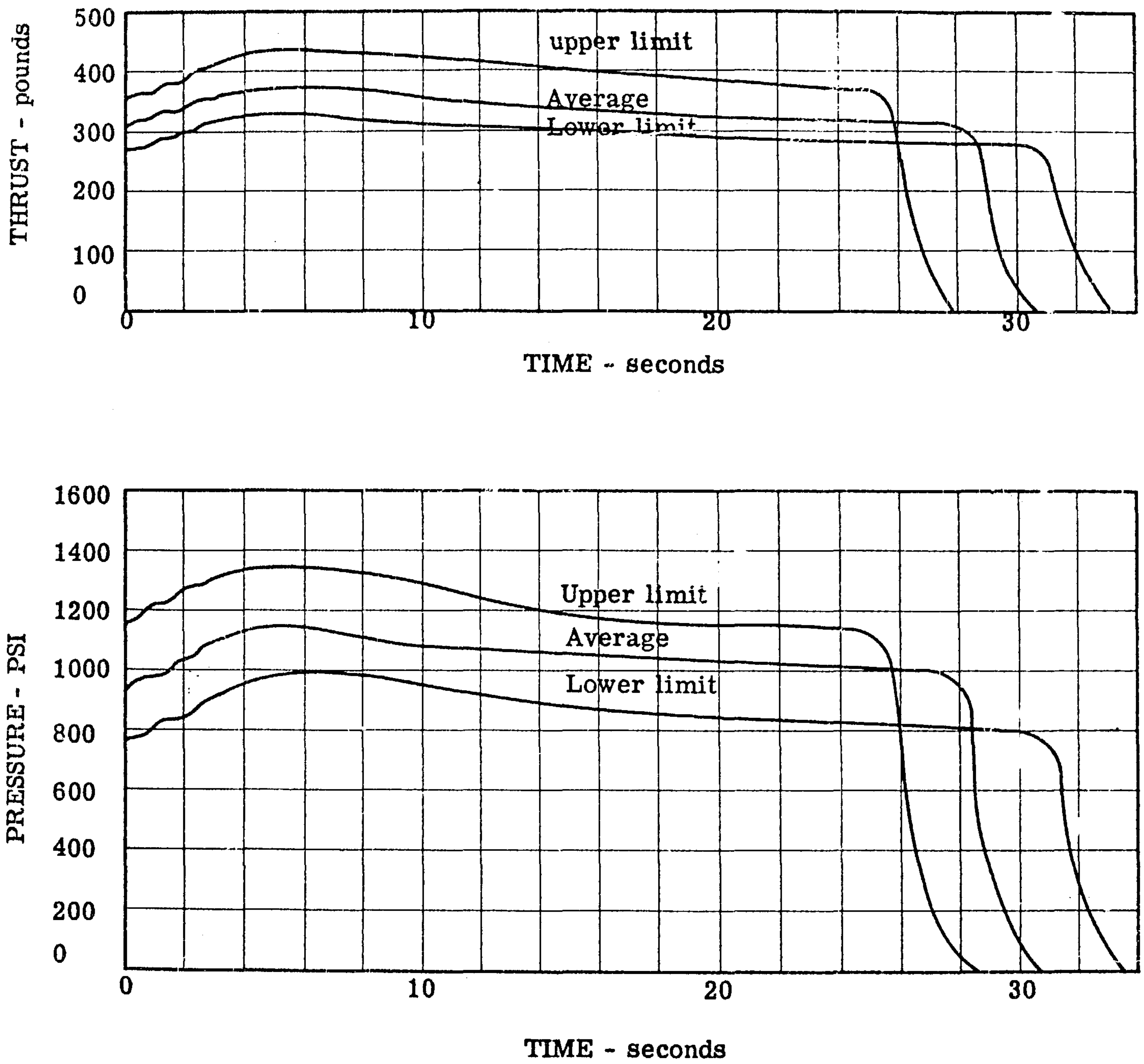

Figure 6. Typical Thrust-Time and Pressure-Time Curves for the Arcas Rocket Motor at 70°F.

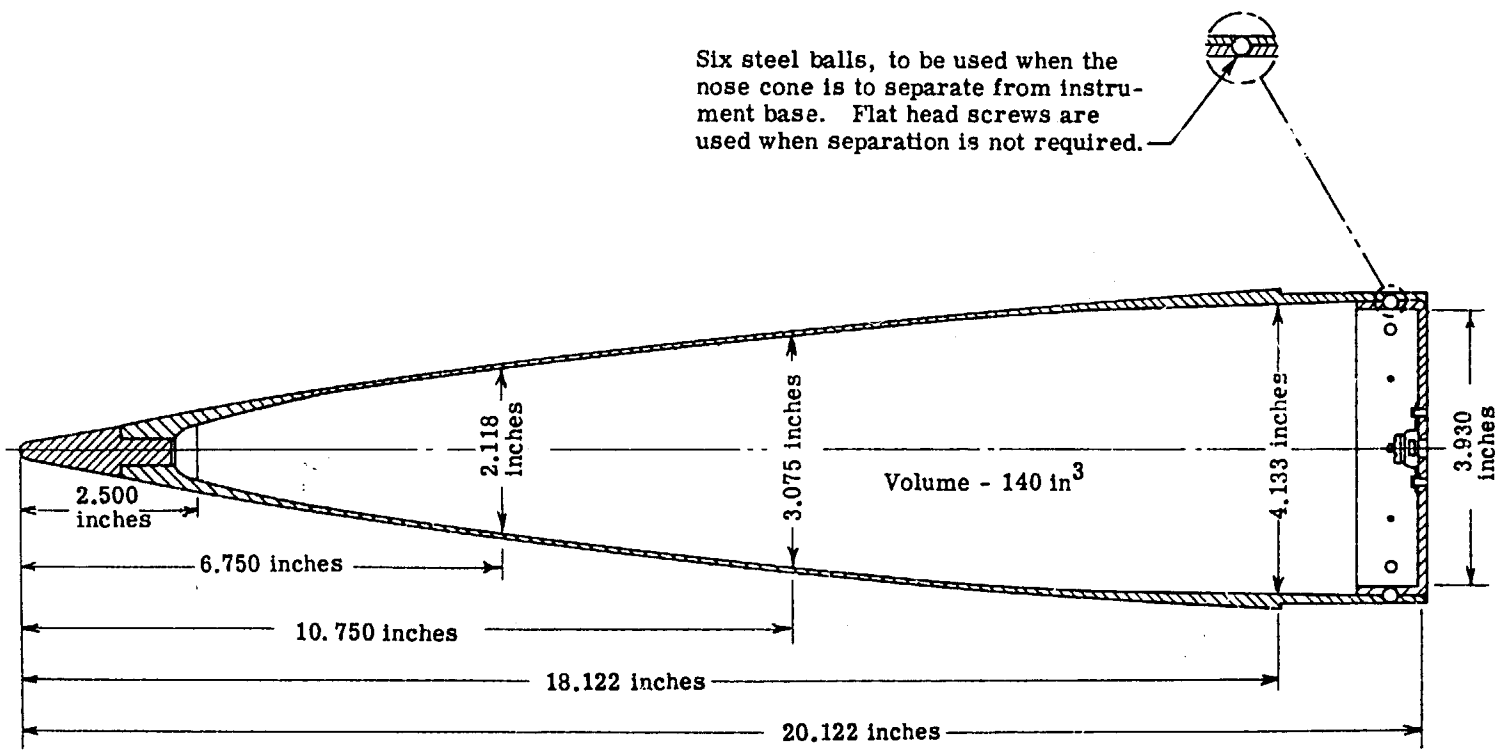

Figure 7. Arcas Nose Cone Assembly.

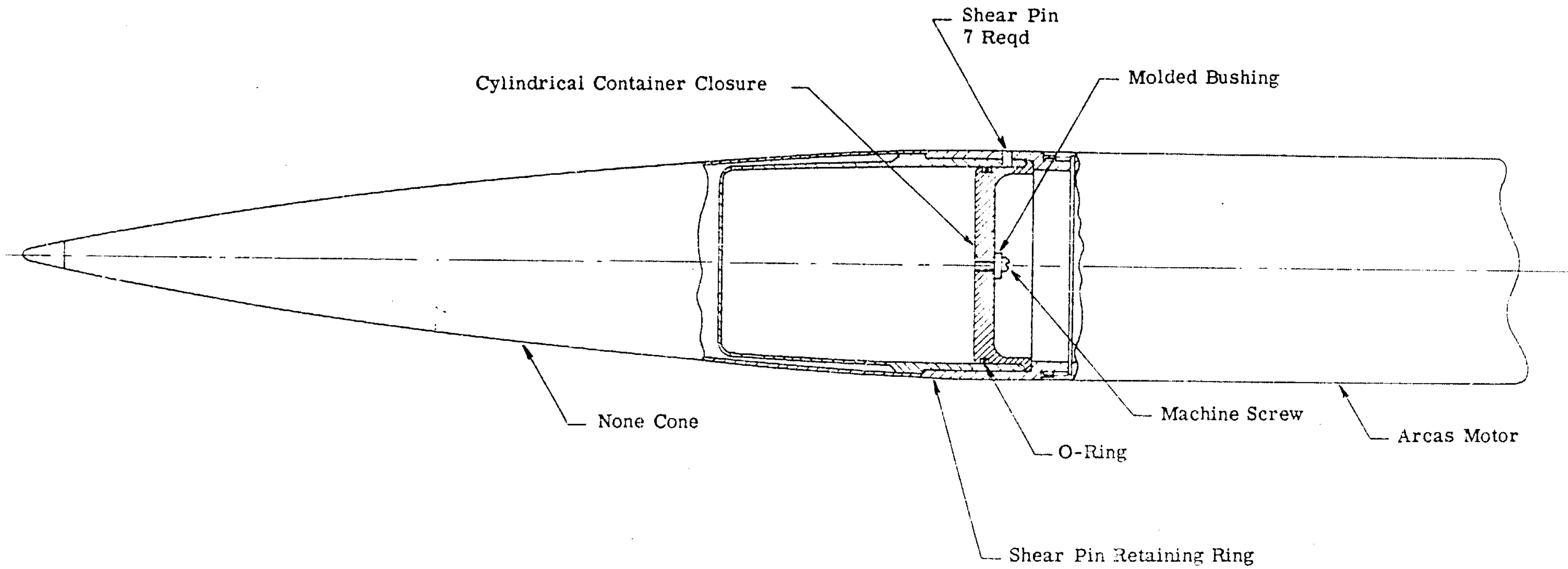

Figure 8. Arcas Robin Balloon Packaging System.

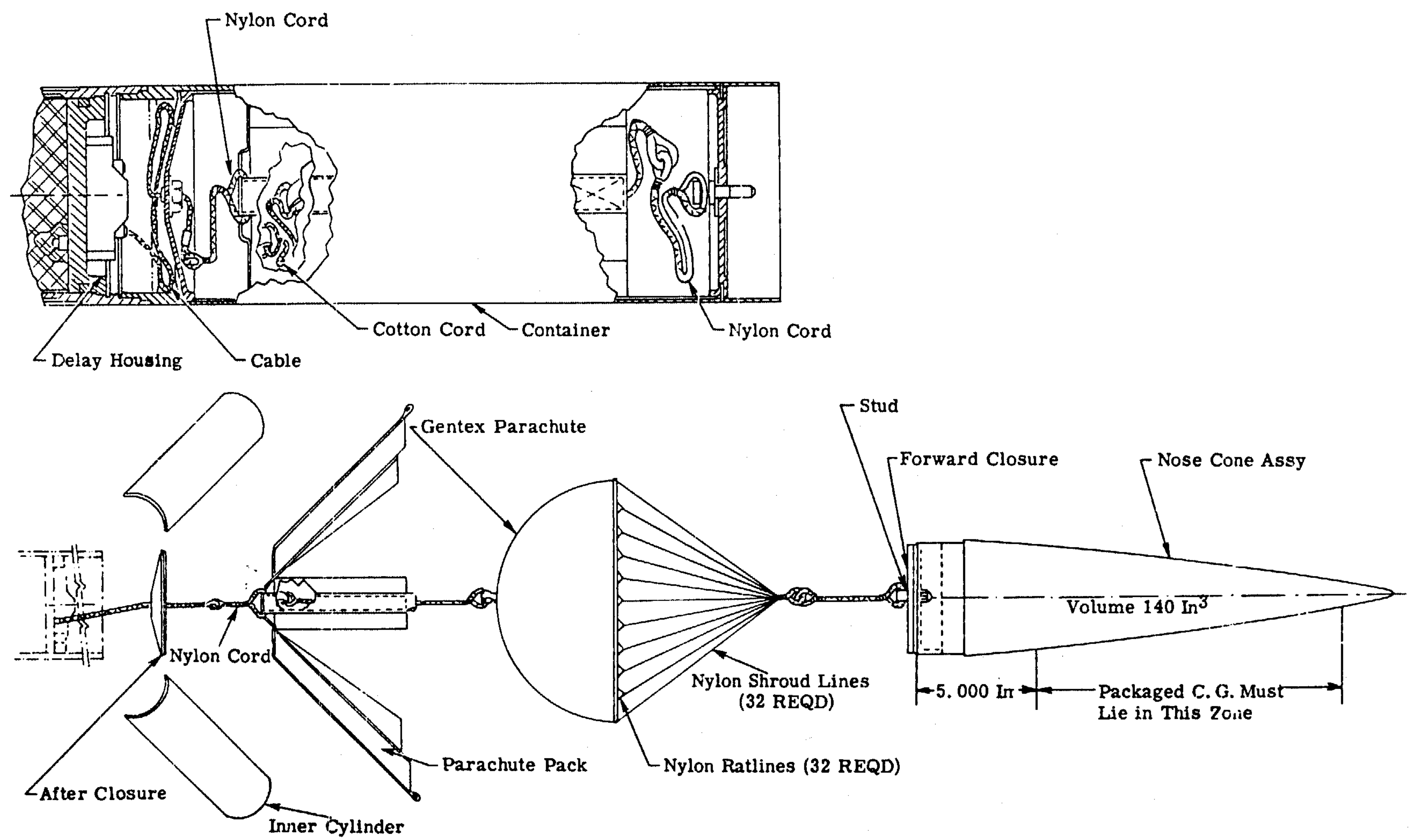

Figure 9. Arcas Parachute System.

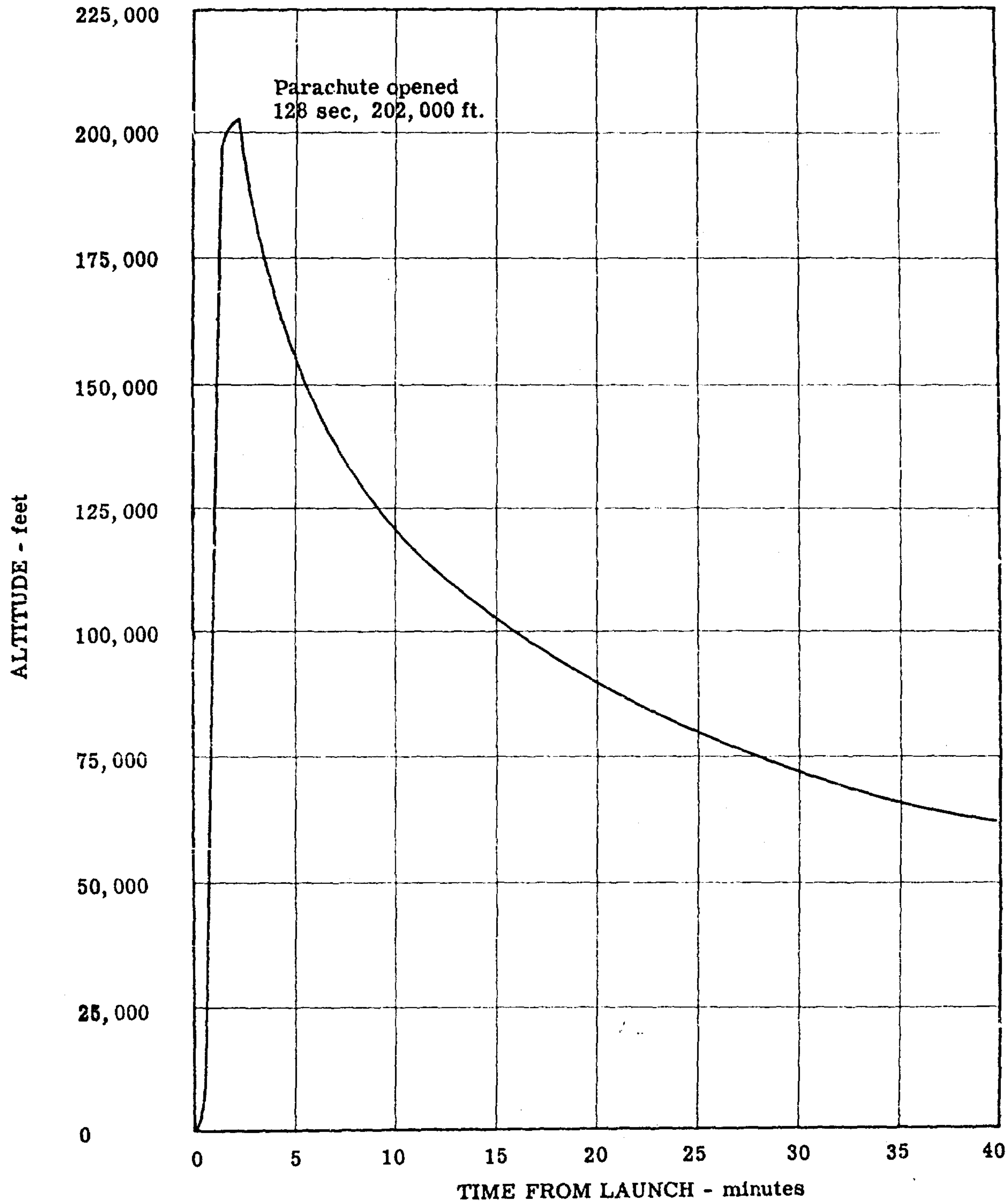

Figure 10. Descent Curve for the Arcas Parachute

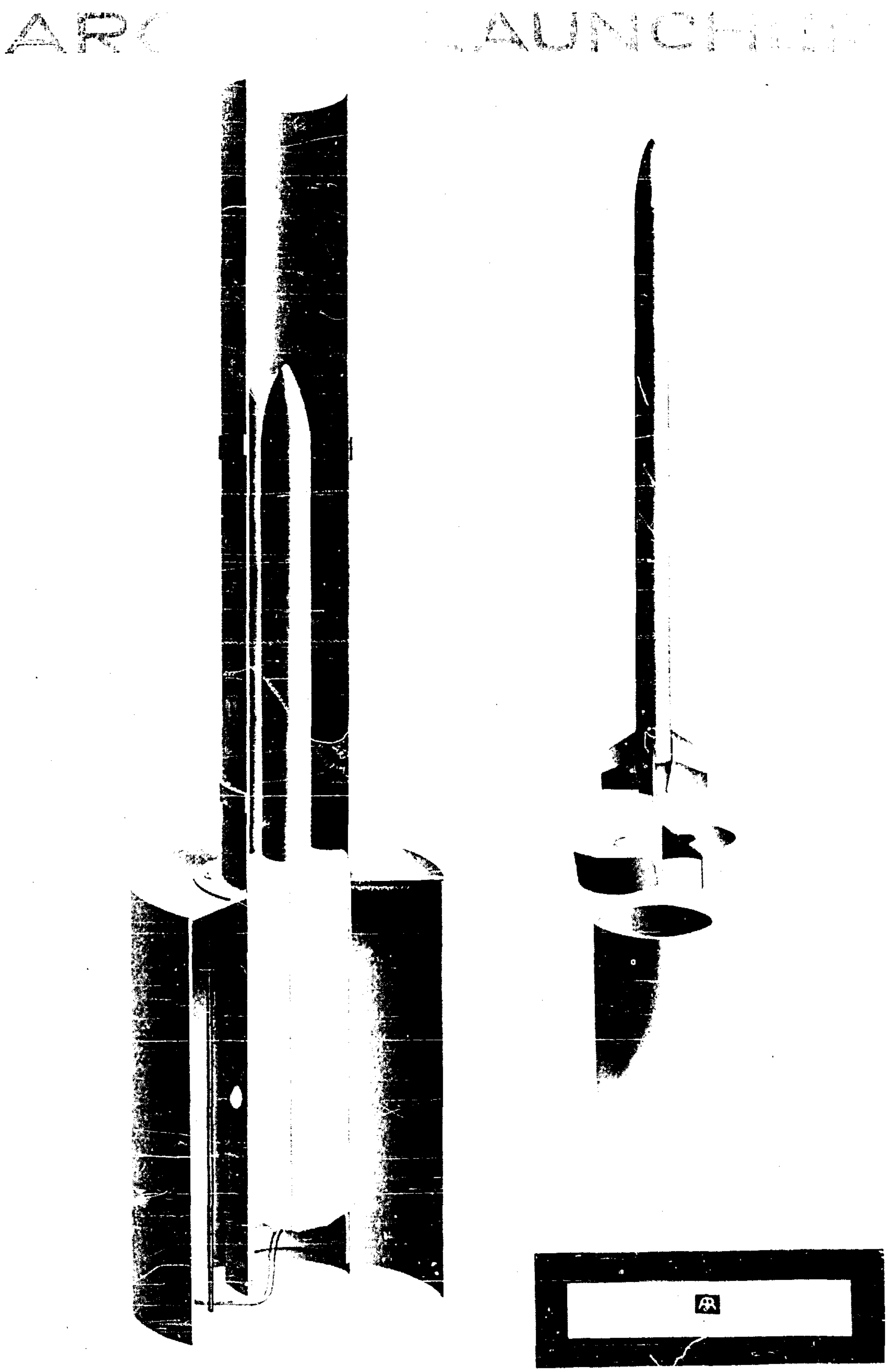

Figure 11. Schematic Illustrating the Principle of the Closed-Breech Launcher

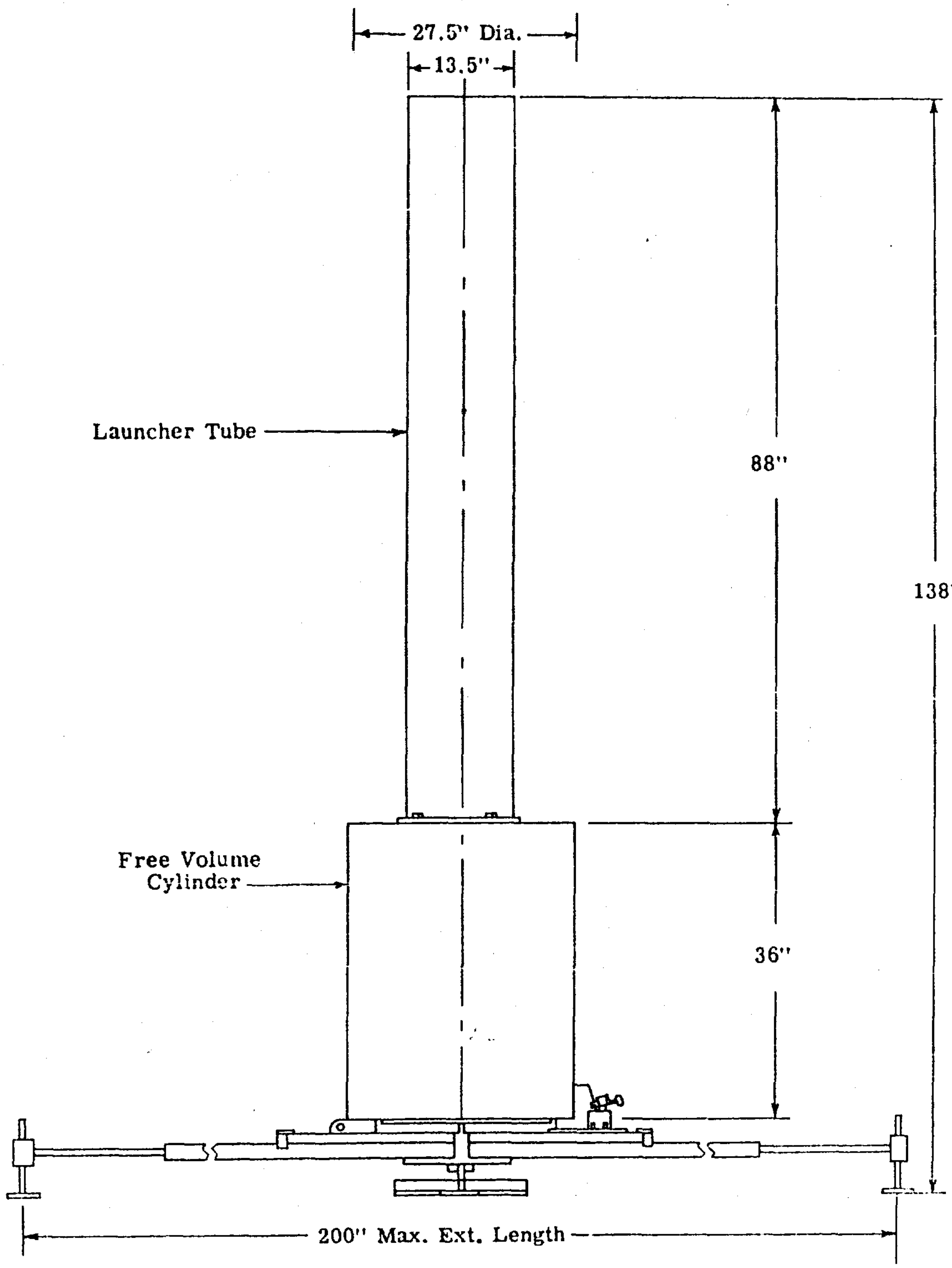

Figure 12. Arcas Model 1 Closed-Breech Launcher

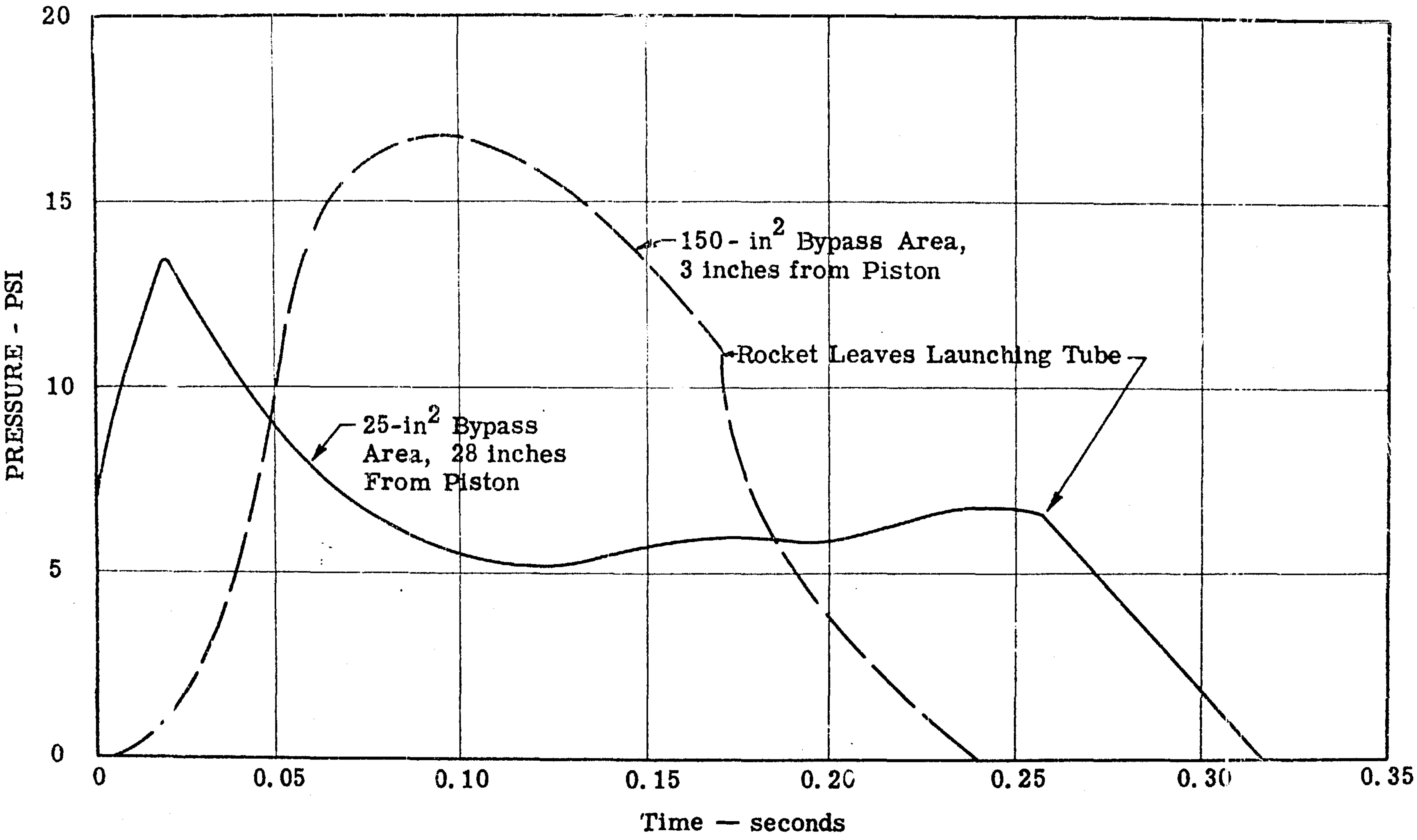

Figure 13. Launcher Pressure Traces for Launchings with the Models 1 and 2 Closed-Breech Launchers.

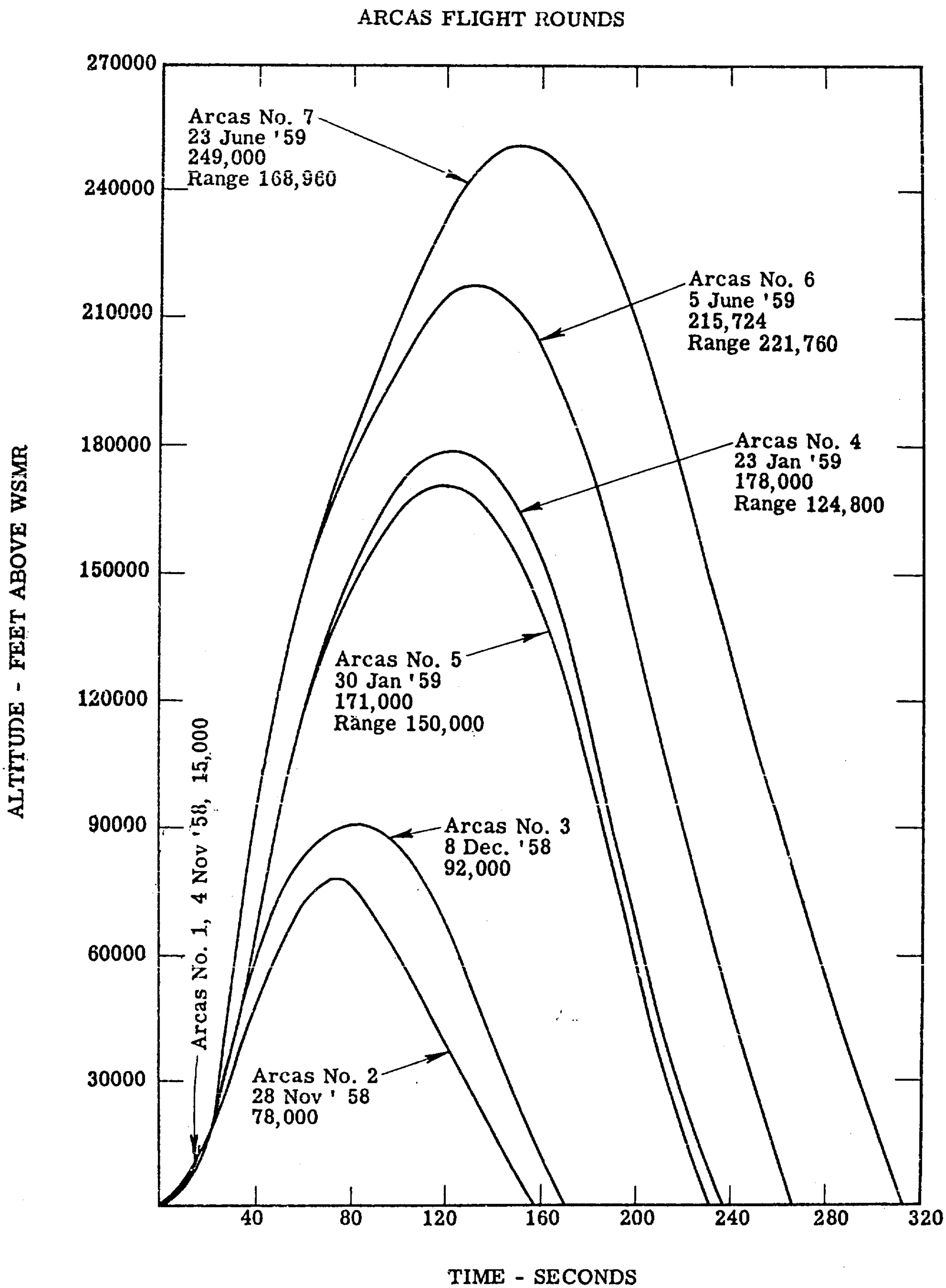

Figure 14. Trajectories of the Seven Arcas Performance Flight Tests.

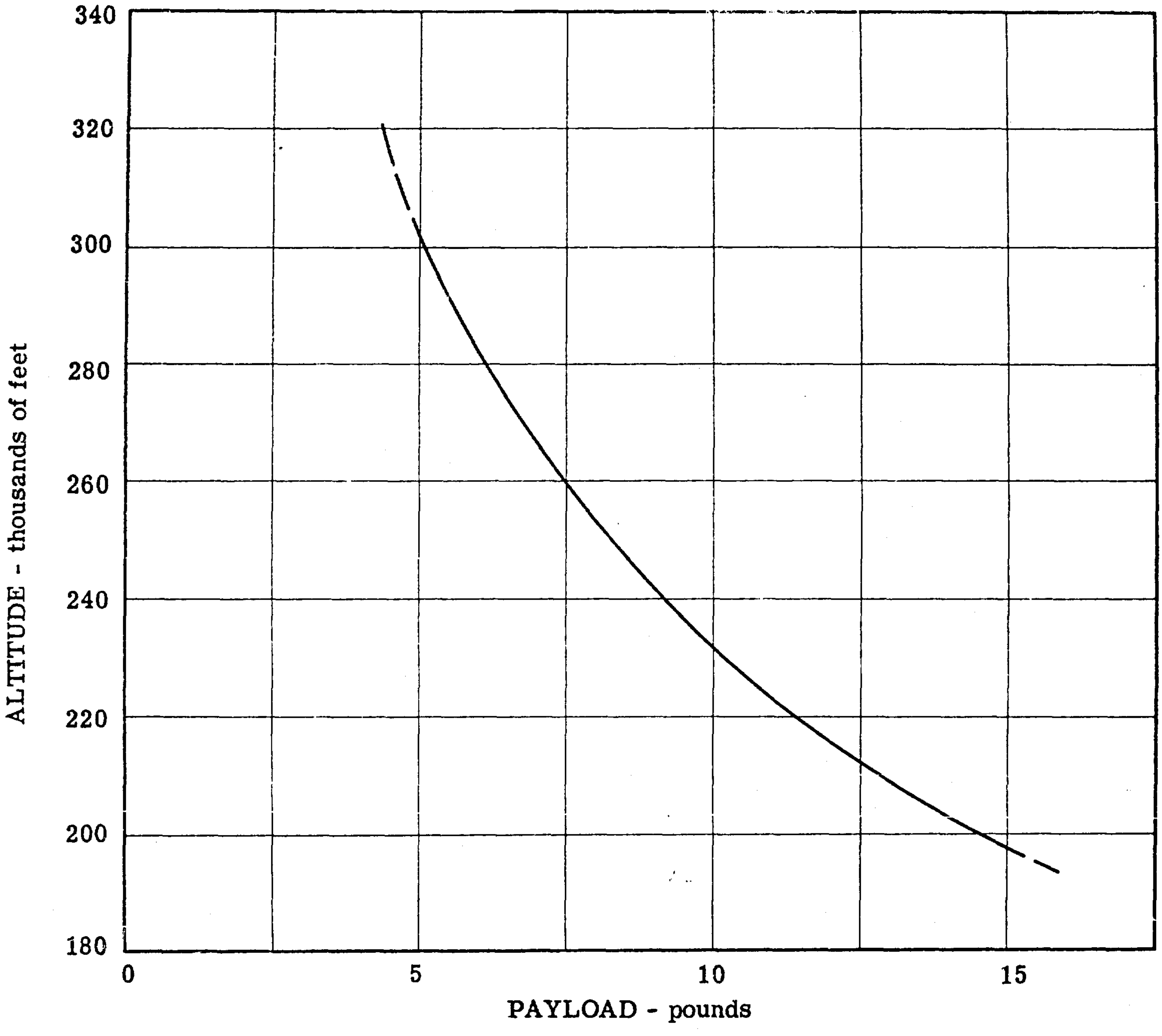

Figure 15. Peak Altitude Attained by the Arcas Missile with Various Payloads

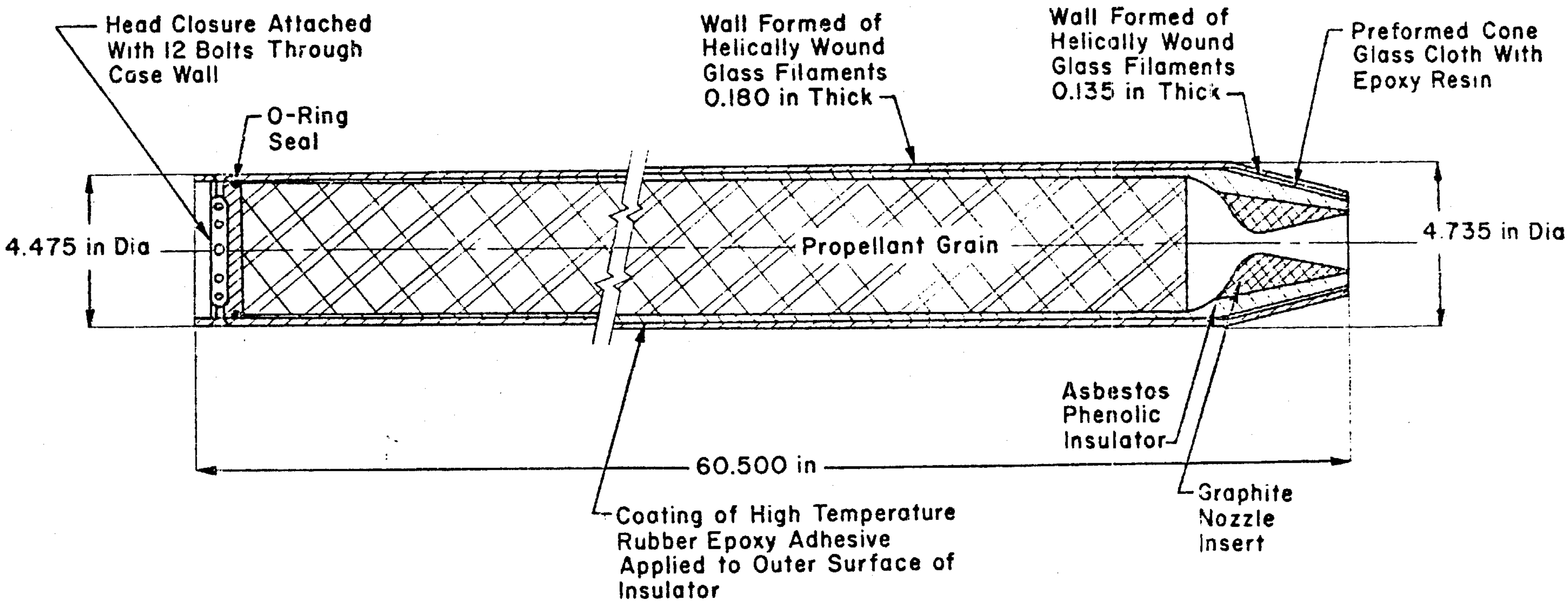

Figure 16. Arcas Fiber Glass Motor Case Design.

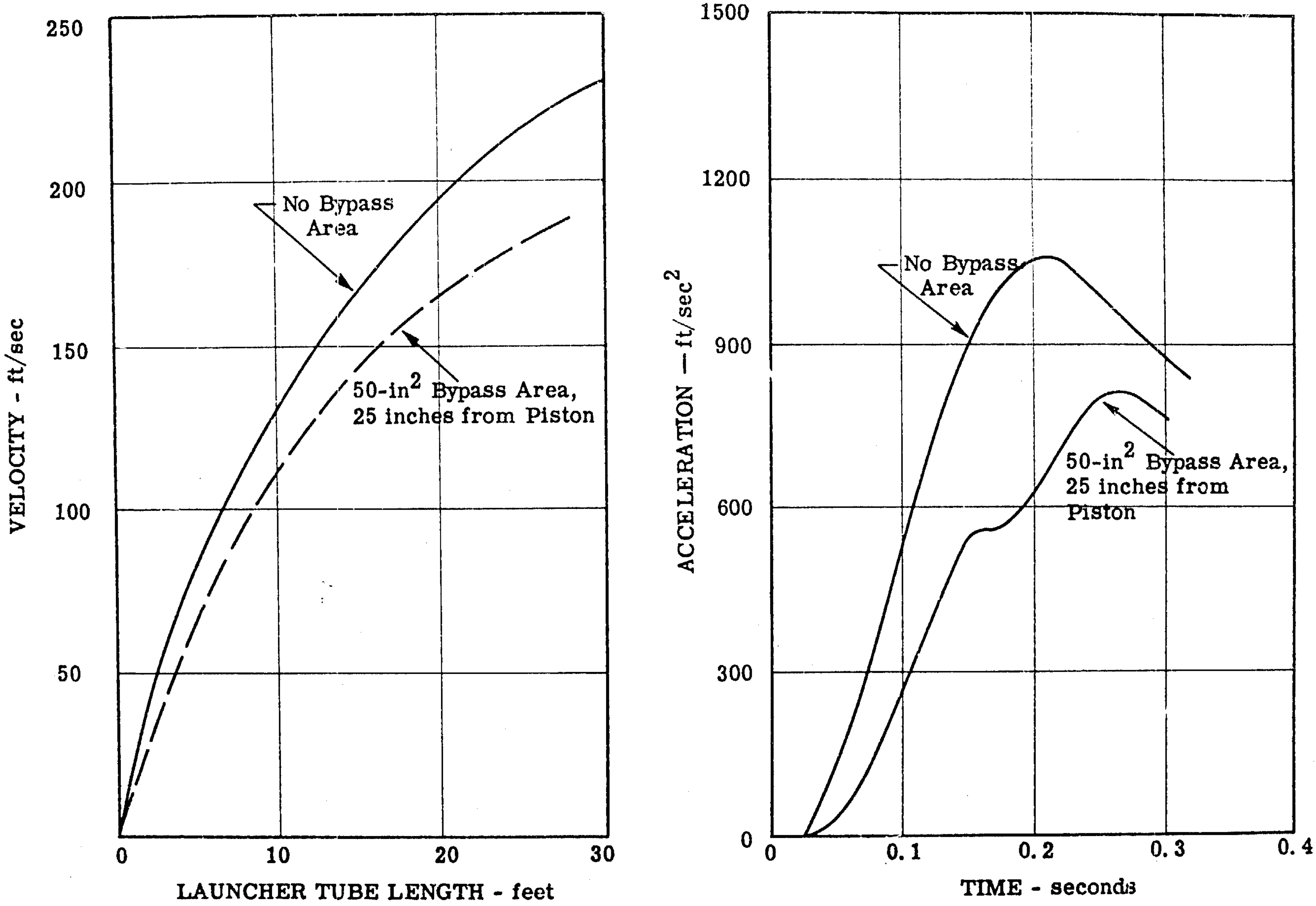

Figure 17. Theoretical Velocity and Acceleration Curves for the Closed-Breech Launcher.

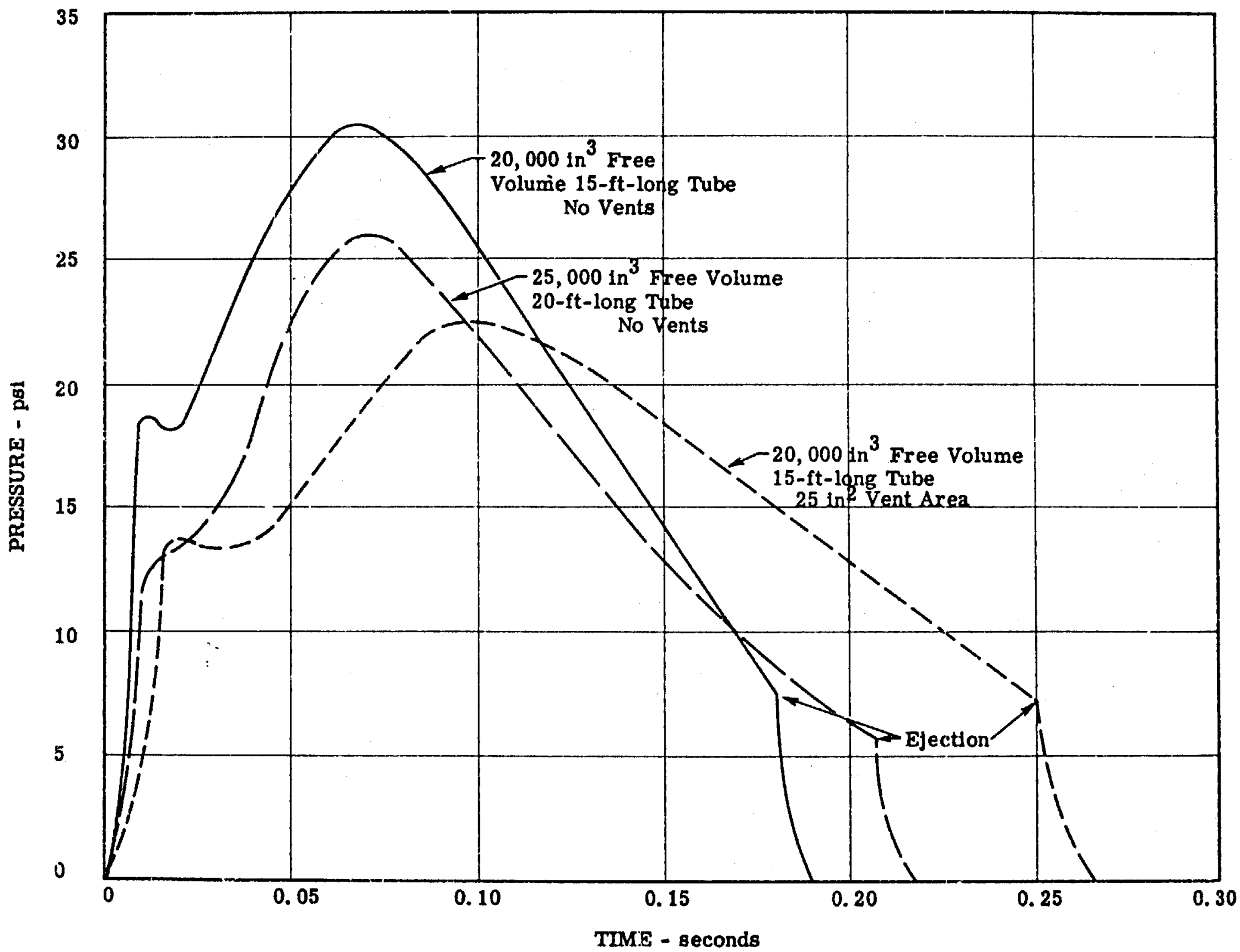

Figure 18. Launcher Pressure Traces for Launchings with Various Configurations of the Closed-Breech Launcher.

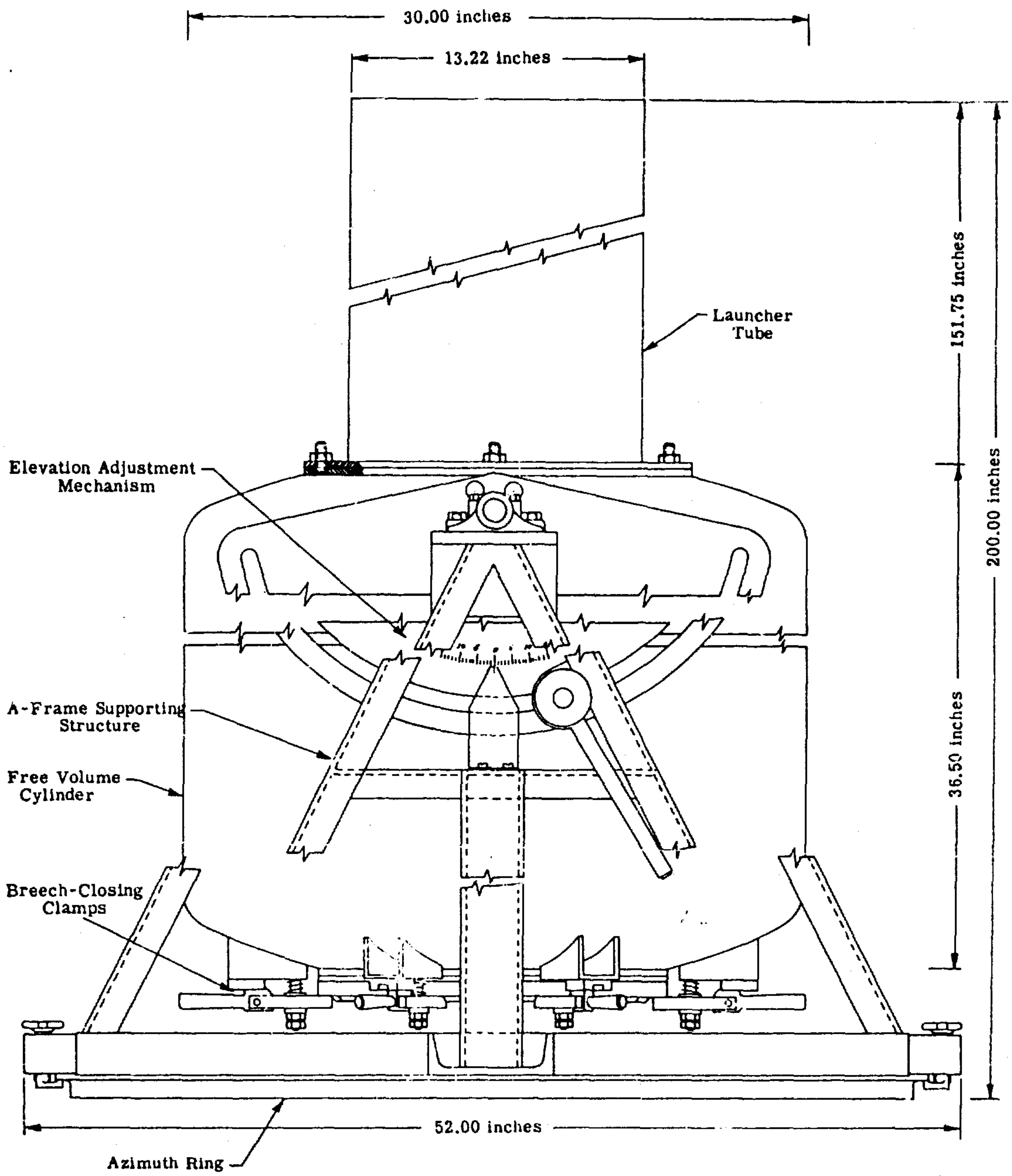

Figure 19. [illegible] Closed-Breech Launcher

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